United States Department of Agriculture

Forest Service

North Central Forest Experiment Station

General Technical Report **NC-162**

Field Sampling and Data Analysis Methods for Development of Ecological Land Classifications: An Application on the Manistee National Forest

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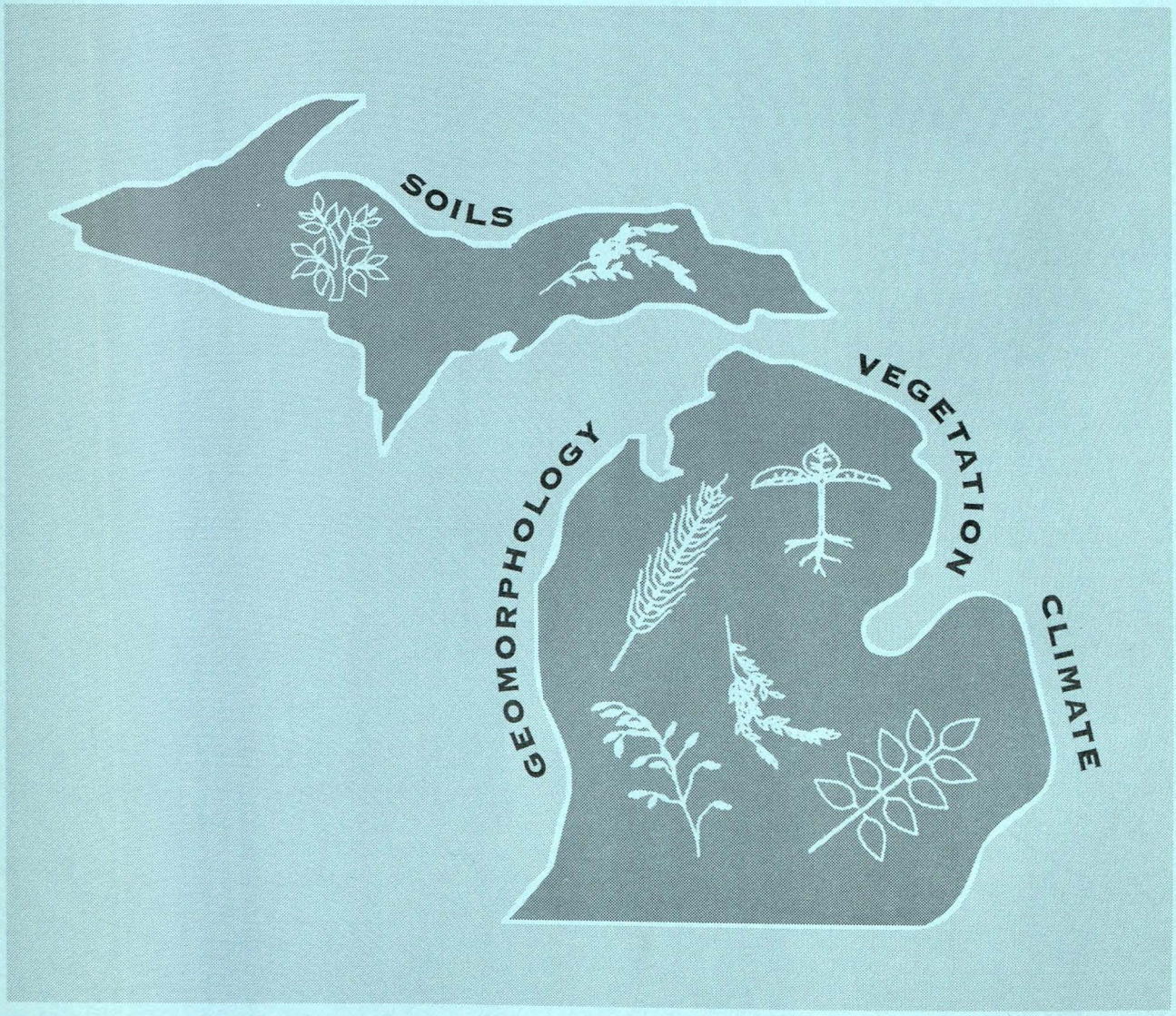
Kurt S. Pregitzer, James B. Hart and David T. Cleland



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North Central Forest Experiment Station
Forest Service—U.S. Department of Agriculture
1992 Folwell Avenue
St. Paul, MN 55108
Manuscript approved for publication September 20, 1993
1993

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INTRODUCTION

An Ecological Classification and Inventory (EC&I) of the Manistee National Forest was conducted to provide the Forest with information needed as an ecological framework for integrated resource planning and management. A non-technical field guide was previously developed that discusses concepts and general techniques used in the Manistee National Forest's EC&I, and describes the ecological types (land classification units) and their identification (Cleland *et al.* 1993). A companion to the field guide, this General Technical Report presents the technical details of the development of the EC&I. It discusses the procedures used for developing the sampling design and methods, specific procedures for sampling vegetation and soils, and techniques for managing and analyzing data. It also describes several alternative data analysis methods useful for analyzing, interpreting, and validating EC& I systems. This report is thus intended to provide technical documentation to support the EC&I developed for the Manistee National Forest as well as to offer a set of procedures for others who may be conducting similar ecological land classification projects.

The development of an EC&I is an iterative process. Analysis of field data may result in a refinement of the ecological type definitions, which may in turn alter the sample design. Both field sampling and the description of ecological types on the Manistee National Forest were based on a conceptual model of the ecological factors that influence ecosystem structure, function, and diversity. These factors, including climate, geology, flora, fauna, and time, are expressed in observable characteristics of ecosystem components, including composition and relative abundance of plant species in all structural layers, soil morphology, and the parent materials, surficial topography, and spatial configuration of glacial landforms (Albert *et al.* 1986, Barnes *et al.* 1982, Barnes 1984, Host and Pregitzer 1992). The conceptual model is best expressed in a figure from Rowe (1984), which shows that, over time, landform and local climate exert strong controls over the co-development of soils and biotic communities (fig. 1). The intent of the EC&I is to identify these volumetric segments of the landscape that differ not only in composition and structure, but also in ecosystem functional processes, such as succession (Host *et al.* 1987), productivity (Host *et al.* 1988), and nutrient cycling (Zak *et al.* 1986, 1989).

Because overstory, ground flora, and soils are sampled with different methods, the procedures for sampling these ecosystem components will be discussed separately. Some analytical methods are applicable to many of the ecosystem compo-

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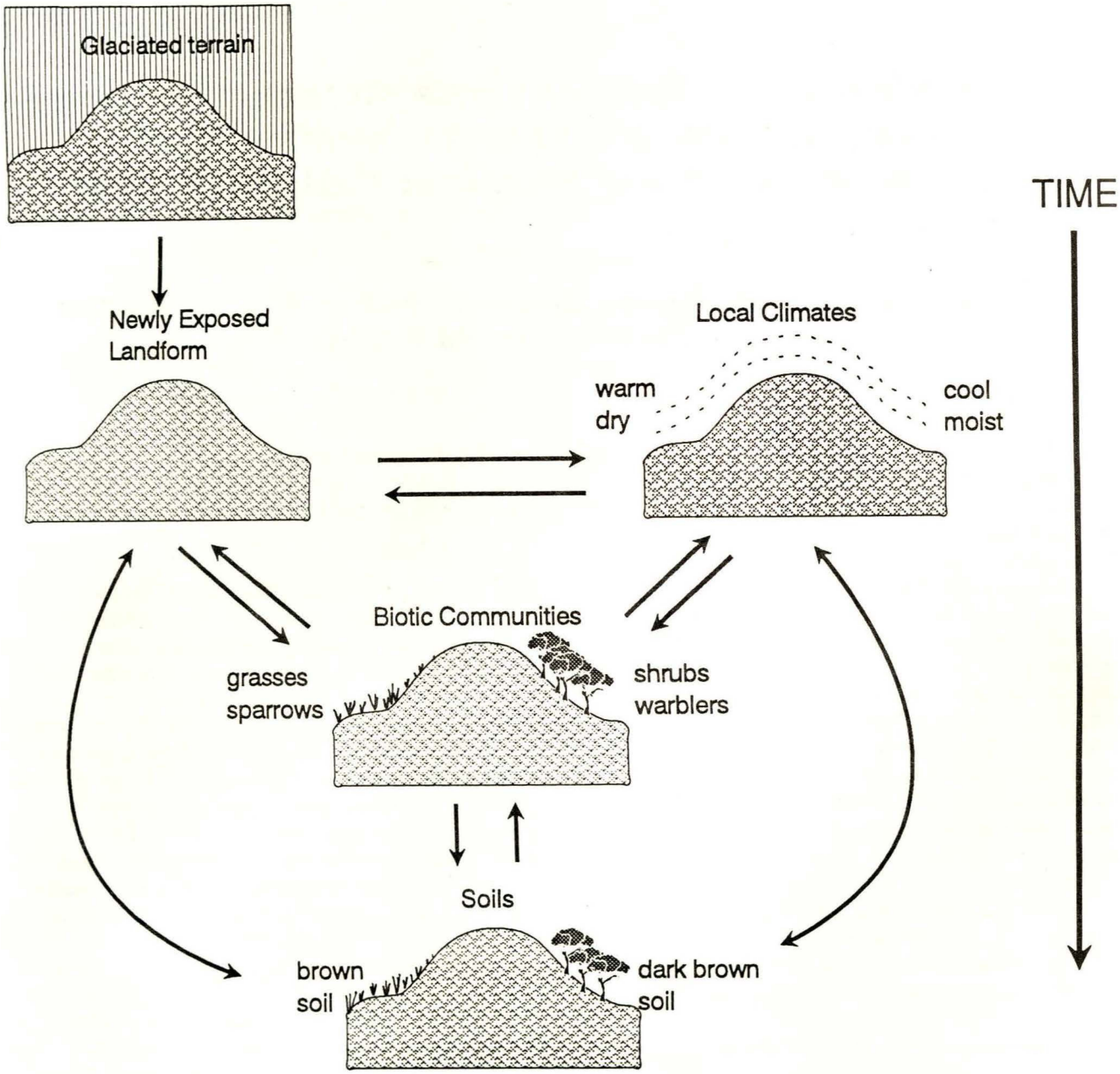

Figure 1.—*Conceptual model showing the co-development of soils and biotic communities as influenced by climate and physiography. Adapted from Rowe (1984).*

nents, or to combined data from several components, while others have been designed specifically for single ecological factors. Results from these individual analyses are integrated to define, characterize, and validate ecological units. This report will describe the process of planning, field sampling, data management and analysis, and EC&I development.

PLANNING THE FIELD STUDY

Sample Design

Before field sampling began, we decided on sampling objectives, information needs, sample unit, sample size, and sampling procedures. The pre-sampling procedures described below are loosely based on Freese (1962) and Williams (1978).

Our sampling objective was to collect and analyze climate, landform, overstory, ground flora, and soil attributes to describe ecological types on the Manistee National Forest. Descriptive information was needed for timber productivity, regeneration, overstory composition and structure, ground-flora composition and abundance, and selected soil characteristics.

The sample population for the EC&I project was defined as well-stocked, undisturbed, even-aged, mature upland hardwood stands. Strata were

defined based on ecological types conceived of through the conceptual model. An ecological type is defined by the Forest Service Manual as, "a category of land having a unique combination of potential natural community, soil, landscape features, climate, and differing from other ecological types in its ability to produce vegetation and respond to management (FSM 2060)." In northwestern Lower Michigan, factors controlling community composition and soil development are closely related to glacial landform, defined in terms of parent materials and surficial topography (Host and Pregitzer 1992). We thus used landform as the primary stratum for sampling. These strata were mutually exclusive; each sample unit was a member of one and only one stratum, sampling was done independently, means and variances were calculated separately, and absolute or relative number of acres in each stratum was known in advance.

A sample frame was constructed to include a list of all stands within the population that matched the stratum's definition. During the first EC&I field season, the Forest Service's Vegetative Management Information System data base was used to construct the sample frame, but many stands were rejected after field inspection. Better results were achieved through photointerpretation of color infrared photographs in conjunction with glacial geology maps (Farrand 1984) and Forest Service compartment maps. The photographs were interpreted using a mirror stereoscope and Hudson's (1984) guide to forest cover types of Michigan.

Sample size may be determined by calculating the minimum sample required to achieve a desired precision (Cochran 1977, Williams 1978) based on relative strata size and strata variability. However, such detailed information usually does not exist for conceptual ecological classes. For this study, overall sample size was set operationally for the first field season by multiplying the number of field crews by the number of field days and by the estimated average number of plots measured per day. This rough sample size was allocated across the strata. Allocation for this study was proportional, based on stratum size, but could be equal or optimal (based on stratum size and variance) in other sampling designs.

The sample unit was defined as a relatively homogeneous upland forested stand of at least 2.5 acres. To minimize the effect of historical differences in stand establishment and environmental variation within stands, we developed criteria for the acceptance or rejection of sample units in the field. These were:

(1) the overstory must be at least 40 years old;
(2) the canopy must be closed, as much as site conditions permit;
(3) density must be uniform throughout the stand; extensive open areas or wide age distributions (range more than 10 years) are cause for rejection;
(4) stand composition must be relatively uniform;
(5) the topography must be representative of upland conditions;
(6) the soils must be moderately well, well, or excessively well drained; mottling in the upper 16 inches is cause for rejection;
(7) aspen must not comprise more than 30 percent of total stand basal area;
(8) no more than 30 percent of the overstory can consist of multiple stems (stump sprouts); and
(9) there can be no evidence of cutting, thinning, underplanting, or other disturbance within the past 40 years.

Stands or sample units that met all the above criteria became part of the sample frame, and sample units were randomly selected from each ecological type, or stratum.

Within the stand, randomly located subplots were established in sufficient numbers to adequately account for within-stand variability. The appropriate number of subplots per stand was determined using a Monte Carlo subsampling method. For the first several weeks of field sampling, we sampled six subplots per stand. We then calculated stand level means and variances based on repeated subsampling using five, four, and three subplots per stand. We found that four subplots were adequate to characterize within-stand variability, and thus used four subplots for the remainder of the study.

A list of variables was identified for each ecosystem component of the conceptual model (i.e. landform, soil, ground flora, and understory and overstory vegetation). These variables are described in their respective sections.

Data Collection and Management

Data forms were designed to be easily compiled into data files for analysis. Data sheets and procedures were tested by the field crews, revised, and re-evaluated. Example data sheets for overstory, ground flora, and soil sampling are presented in Appendix A.

A data management system was designed to include procedures for collecting, compiling, checking, verifying, and summarizing the data. Software was tested before field sampling began to ensure that any specific information required by the programs could be collected. We did not use portable data recorders because they were still in a relatively primitive stage of engineering at the time the project began, but we do recommend them for similar future work. Their use would permit error checking in the field and significantly reduce time spent in data compilation and entry.

Field Crew Training and Supervision

Field crews generally consisted of three persons who had technical expertise in the disciplines of soils, forestry, and botany. The field crew was trained for at least 1 week at the beginning of the field season. The supervisor made visits to each field crew and repeated the crew's sampling procedures at one or more sample points. Field checks were continued throughout the field season for quality control. Accuracy and precision in measurements had top priority.

FIELD SAMPLING PROCEDURES

Stand and Subplot Selection

After the pre-sampling procedures were completed, field sampling began. Steps used in selecting and establishing sample stands and subplots on the Manistee National Forest are given below.

1. Randomly selected stands from each stratum were visited in the field and evaluated using the rejection/acceptance criteria.

2. If the stand met the acceptance criteria, a homogeneous area (minimum size 2.5 acres) was identified as the location to be sampled.

3. Stand location was identified by Ranger District, Forest Service compartment and stand number, and distance and direction from State, county, and local roads. Its legal description was also recorded: location within the section, section number, township, range, and county.

4. The first subplot was established near the center of the 2.5-acre homogeneous area. Subsequent subplots were selected using tables of random azimuths and distances (Appendix A). Distance and direction from the first subplot to each subsequent subplot were recorded, and subplot centers were marked with permanent stakes (metal or PCV).

Overstory Sampling

Both variable-radius and fixed-area plots were considered when deciding how to measure overstory composition and productivity for the EC&I. Variable-radius sampling was selected for its increased efficiency and reduced time per sample unit, despite the possibility of operator error associated with this method. Because the use of wedge prisms can result in erroneous stand density and volume estimations, we used Relaskops, which are not as sensitive to handling errors, and which automatically compensate for slope. For discussions about the problems associated with point sampling, see Iles (1989), Wiant (1987), Wensel *et al.* (1980), Wiant *et al.* (1984), and Gambill *et al.* (1985).

A variable-radius sample plot, or prism point, was centered upon each randomly placed subplot to measure overstory characteristics. Starting from due north and proceeding clockwise, all visible trees were scanned at diameter at breast height (d.b.h.) using a Relaskop and a preselected BAF, and tally trees were identified. A 20 BAF was used for well-stocked sawtimber stands; a 10 BAF was used for poorly stocked sawtimber stands and for pole stands. All sample points within a research site used the same BAF.

All live tally trees were measured for d.b.h., species, total height, crown ratio, and crown class. Merchantable height was estimated for all live tally trees of more than minimum merchantable d.b.h. All borderline trees were measured to determine if they should be tallied. Tally trees were marked with a chalk gun at d.b.h. This allowed one person to take individual tree measurements once the tally trees were marked, thereby reducing field time. Tally trees were numbered sequentially on each sample point, starting at due north and moving clockwise.

Species was recorded as a two-digit code. D.b.h. was measured using a diameter tape and recorded to the nearest 0.1 inch. Total height and merchantable height were measured to the nearest foot using a Relaskop. A logger's tape was used to measure horizontal distance from each tree before estimating height. Horizontal distance had to equal or exceed the estimated height of the tree to avoid errors in determining total height. For cubic foot volume, merchantable height was measured from a 1-foot stump height to a 4-inch top diameter, or to where merchantability was limited by the bole. The Relaskop's optical dendrometer was used to determine the upper stem diameter and height.

Crown class was ocularly estimated. It was coded as: (1) open grown, isolated; (2) dominant (light from above, sides); (3) codominant (light only from above); (4) intermediate; or (5) suppressed or overtopped.

Crown ratio was also ocularly estimated. It was expressed as a percent of total tree height, scaled and recorded as a one-digit code. The crown ratio was defined as that portion of the tree bole that supports green, live, healthy foliage that is effectively contributing to tree growth. The codes used for crown ratio were:

1: live crown <= 10% of total tree height
2: live crown 11% - 20%
3: live crown 21% - 30%
4: live crown 31% - 40%
5: live crown 41% - 50%
6: live crown 51% - 60%
7: live crown 61% - 70%
8: live crown 71% - 80%
9: live crown 81% - 90%

Four tally trees (d.b.h. more than 4 inches) were sampled for 10-year radial diameter growth at each sample point. We selected these trees at random, but tried to sample across the range of diameters and species. Increment cores were taken immediately below d.b.h., at right angles to the bole. Radial growth was recorded to the nearest 0.1 inch.

Two dominant, uninjured, and free-growing trees on each sample point were bored for age at d.b.h., which was converted to total age and used with total height to estimate site index (Hahn and Carmean 1982). Additional trees off the sample point but within the stand were measured to provide ancillary site index data for major commercial species.

Ground-Flora Sampling

Plot size and shape

Optimum plot sizes for sampling ground flora are typically determined by constructing species-area curves. These curves are constructed by counting the numbers of species within progressively larger sample plots until increases in plot size do not result in significant increases in species number (i.e. the curve levels off). Although this approach is important in developing sampling strategies for previously unexplored landscapes, species-area relationships are fairly well developed for North American ecosystems. Gauch (1982) suggests plots of 100 to 500 m^2 for sampling abundance patterns in temperate deciduous forest communities. Square, circular, and rectangular plots have all been successfully used to quantify vegetation abundance; rectangular plots are more likely to include patches of different species. Counts of individuals (e.g. tree seedlings) are best sampled using a number of smaller (0.5 to 1 m^2) plots nested within the larger plot. The number of smaller plots required depends on the desired level of precision (Kupper and Hafner 1989).

Quantifying species abundance

Species abundance can be quantified by various methods, including point frames, line intercepts, destructive harvesting, and ocular estimation. The method used must be a balance between the precision required and the number of plots or amount of land area to be surveyed. For the multivariate methods used to construct the Manistee National Forest's EC&I, we found ocular estimates of coverage to be the most

effective and expedient means of quantification. Extensive research into developing optimized scales for measuring coverage has found that scales that are logarithmic or have finer levels of resolution in the lower cover classes are most effective for capturing ecologically important information. See Gauch 1982, Causton 1988, and Bonham 1989 for detailed discussions on this subject. We used a modification of the Braun-Blanquet releve scale (table 1).

Table 1.—*Cover-abundance classes and ranks used in field sampling and data analysis*

Class midpoint	Range of cover	Rank
	Percent	
r	Trace - 0.1	1
+	0.1 - 1.0	2
2	1 - 2	3
10	2 - 15	4
25	15 - 33	5
50	33 - 66	6
80	66 - 100	7

Methods

Ground-flora composition and abundance were sampled using four 5- x 30-m plots centered on the overstory sample points. In flat terrain, plots were oriented on north-south axes. In hilly terrain, plots were generally oriented perpendicular to the slope to avoid sampling across different physiognomic conditions.

Average percent ground cover was determined for all moss, herbaceous, and woody species in the plot using the modified Braun-Blanquet cover-abundance scale shown in table 1 (Mueller-Dombois and Ellenberg 1974). The plot was traversed several times to record the species present and abundance values were assigned based on ocular estimates. Relative frequencies for ground-flora species were determined by recording presence/absence of species in six 1-m^2 frequency frames located at 5-m intervals along the long axis of each plot. These frequency frames were also used to determine seedling densities in a subset of sample plots (Host *et al.* 1987). Saplings (defined as stems of trees and shrubs with a d.b.h. of at least 0.5 inches) densities were determined using stem counts in the 5- x 30-m plots. Saplings were tallied in 1-, 2-, and 3-inch diameter classes (d.b.h.). Nomenclature for vascular plants followed Gleason (1952); nomenclature for bryophytes followed Crum and Anderson (1981). Samples of unknown species were collected, pressed, and identified at the Michigan State University Beal-Darlington Herbarium.

Soil Sampling

Depth of soil observations

Soil extended from the forest floor layers at the upper surface, to a depth coincident with the lower limit of biological activity, or, the maximum rooting depth of native perennial plants (Soil Survey Staff 1975). On the Manistee National Forest, tree species have rooted to depths as great as 15 feet in stratified sandy and loamy sand materials. Therefore, information was collected to a depth of 15 feet in soils that were predominantly sandy.

In pedons with continuous heavy-textured soil more than approximately 3 feet thick, rooting was usually restricted. In these cases, soils were observed to a depth extending 3 feet into sandy clay loam or finer material where there was no evidence of deeper rooting.

We believe that the rooting zone was adequately described, in nearly all the sandy soils, by a 15-foot deep observation. Data were usually not collected below 15 feet; bucket auger sampling is impractical below that depth because soil sloughs off the sides of the hole, refilling it in amounts almost equal to that removed by each auger sample.

Quantification of textural banding

Sandy soils that contain fine-textured layers, or bands, have been shown to support different tree species and faster overstory growth rates than soils without banding (Hannah and Zahner 1970, Cleland *et al.* 1985, Host *et al.* 1988). It was therefore important to record the presence, texture, and thickness of deep-lying textural bands within a 15-foot depth. A Banding Intensity and Continuity variable (BIC) representing substratum characteristics was described categorically for each soil (table 2).

Table 2.—*Banding intensity and continuity (BIC) codes for soil textural bands*

Banding class	**Code**	**Remarks**
Unstratified sands CS, MS)*	0	Usually CS to MS predominately in sandy outwash (VCS, plains. FS unlikely.
Varved sands (VCS, CS, MS, FS)	1	Usually VCS to MS, may have gravel strata. Colored thin layers associated with darker mineralogy and/or sesquioxide staining. Predominately in ice-contact sandy low hills or sandy outwash areas.
Stratified sands with loamy sand strata	1	Similar to above but with LS textural varves, lenses, or lamellae. Thick LS strata rare.
Sandy loam textural bands < 2 inches thick	2	Usually VCS to MS, may have gravel strata. Predominately in ice-contact sandy low hills or sandy outwash areas. Would include rare loam bands.
Sandy loam textural bands 5-15 cm thick -OR- Sandy clay loam (or heavier) textural bands < 4 inches thick	3	Usually VCS to FS, may have gravel strata. Predominately in ice-contact sandy low hills or sandy outwash areas. SL bands continuous or discontinuous. SCL or heavier bands frequently discontinuous. Would include rare loam bands.
Sandy loam textural bands > 6 inches thick	4	Usually VCS to FS, may have gravel strata. Predominately in ice-contact sandy low hills or sandy outwash areas. SL bands usually continuous.
Sandy clay loam (or heavier) textural bands > 4 inches thick	5	Usually MS to FS, may have gravel strata. Predominately sandy overwash with buried glacial lacustrine lake bed deposits. SCL or heavier bands nearly always continuous and thicker than 6 inches.

* VCS - very coarse sand texture
CS - coarse sand texture
MS - medium sand texture
FS - fine sand texture
VFS - very fine sand texture
LS - loamy sand texture
Sandy - any of above textural classes
SL - sandy loam texture
L - loam texture
SCL - sandy clay loam texture
Heavier than SCL - includes silt loam (SiL), silty clay loam (SiCL), clay loam (CL), and clay (C) textural classes.

Methods

The forest floor, soil solum, substrata, and groundwater characteristics were described at four subplots within each stand. A soil pit was located as close as possible to the center of the overstory sample plot. The exact location of the soil pit within the subplot was determined based on the absence of depressions, mounds, trails, trees, stumps, rocks, other obstructions, or other atypical microsite conditions.

A square soil pit was dug to a depth of 60 inches, with horizontal dimensions of approximately 3.3 square feet. Soil morphological characteristics were described at a modal location on an undisturbed pit face. All soils were described into the C horizons; in sandy soils, descriptions were obtained to depths of 15 feet. Substratum soils were described from samples obtained by augering into the bottom of the soil pit with a 3-inch diameter bucket auger.

Forest floor and soil horizon characteristics were described, including color, texture, coarse fragments, mottling, structure, consistence, reaction, clay films, boundaries, and rooting. Standard Soil Conservation Service techniques were used to describe soils (USDA, Soil Conservation Service 1981).

Bucket auger samples of substratum material were removed in 6 inch or smaller increments while measuring depths and horizon thicknesses. Substratum soil properties were described from auger samples, and included color, texture, coarse fragments, mottling, reaction, and rooting. Horizons were named according to standard protocols; a possible substratum horizon sequence is: C1, C2, C3, IIC4, IIIC5, IIIC6.

Hydrologic features were recorded, including depths of mottling, wetness, and saturation.

Soil samples were collected for laboratory analysis. The solum was sampled from the soil pit by taking representative subsamples from each horizon around the pit faces, and mixing. The substratum was sampled by combining auger samples from the same horizon on a plastic sheet, mixing, and subsampling. Samples were air dried in brown paper bags, and stored for future use. Samples were usually collected from all horizons at the first soil pit of each stand and for uniquely different soil materials at the other three points.

Landform Description

Landform characteristics were recorded at each stand. Local topographic features, such as slope steepness, shape, aspect, and relative position on the landform, were recorded for each subplot. Elevations were determined from U.S. Geological Survey 1:24,000 topographic maps. Existing landform maps (e.g. Farrand 1984) combined with field observations were used to verify the glacial landform (e.g. ground and end moraines, ice-contact hills, terraces, deltas, and outwash plains) surrounding the stand. Landtype Association designations, a physiographic delineation used by the Forest Service (FSM 2060), were obtained from existing maps, and recorded with the landform data.

DATA MANAGEMENT AND SUMMARIES

Overstory

Data compilation and verification were started as soon as possible after field sampling was completed. This allowed resolution of data inconsistency problems while the field crews' memories were still fresh.

The data were compiled and edited using previously developed programs. Programs in QuickBASIC and PASCAL had been written to compile the Manistee productivity data. These programs contained the first level of data checking, which alerted users if a data value (species code, tree d.b.h., crown ratio, etc.) was not within predefined limits.

The second level of data checking was to perform random file checks. A random sample of 5 percent of the field points was selected after the data had been compiled. We printed the computer files from the randomly selected sites and visually compared the data to the original data sheets. If more than 1 percent of the information was in error, all data files would be checked against the original field sheets.

Examples of preliminary data summaries are given in Appendix B. These summaries were produced from a QuickBASIC program developed

by one of the authors (Ramm). Density and volume per acre, age, site index, and growth were estimated for each sample point. Mean density and volume per acre, along with associated standard errors and coefficients of variation, were estimated for the stand.

The preliminary summary program also constructed an ASCII file for each stand: a list of the individual tally trees organized by sample point. The file contained the following information for each tally tree: stand number, subplot number, tree number, d.b.h., species, total height, merchantable height, estimated trees/acre, estimated volume/acre, crown class, and crown ratio. These files were used for intermediate data processing and for summary statistics. It was relatively easy to transfer the data from ASCII files to a data base.

A relational data base program may be more efficient for data compilation and file construction. One data base would contain location and description of each stand; a second data base would contain one record per tally tree, with representative basal area, volume and trees per acre calculated internally. Efficient microcomputer-based relational data base programs were not yet available at the time of this study.

Secondary data processing included the construction of stand and stock tables. Gross cubic foot volume was calculated for the preliminary stand summaries using Beers' version of the Gevorkiantz formula (Gevorkiantz and Olsen 1955), a composite volume equation that has shown good performance in the Lake States (Martin 1984). Site index was estimated using equations developed by Hahn and Carmean (1982).

Ground Flora

As in the overstory analyses, custom programs were written to enter, verify, and summarize the ground-flora data. In the early phases of the study, microcomputer applications software such as spreadsheets and data-base managers were not available for general use. As software such as Visicalc and Lotus became available, data were transferred and summarized using commercial applications software. Quality assurance methods such as those described above were also applied to vegetation data. Data were maintained in ASCII format to allow processing with various applications software.

Data summaries for vegetation data included mean cover, mean rank abundance (table 1), frequency, and importance values summarized across stands and the initial sampling strata. An important consideration in analyzing vegetation data is how to treat the large number of zeros present in the data matrix. It is difficult to separate species absent by chance from those absent because they are not physically capable of persisting on a site. In addition, the inclusion of zeros as data values often yields average coverage values that may never be found in nature. Our solution to this was to calculate mean cover when present (i.e. average only non-zero values) and calculate a frequency statistic to express how often a species is likely to occur. These two statistics were synthesized into an "Importance Value" by multiplying the coverage-when-present by the frequency. Mathematically this is identical to averaging in the zero values, but will not be misinterpreted as a mean coverage value. The use of mean rank abundances tends to linearize the logarithmic cover-abundance scale, making these mathematically more tractable as inputs to multivariate analyses (Gauch 1982). Stand-level mean rank abundances used in developing the Manistee National Forest EC&I are presented in Host (1987). Additional summary statistics can include species richness (number of species per plot or stand) and other indices of species diversity.

Soils

After field data were collected, the information was transferred to the summary form shown in Appendix B. Information on location and landform was entered directly in data-base files. Soil, geologic, and hydrologic information from the four subplots at each stand was examined, and information was extracted to quantify variables characterizing each subplot.

Our objective was to formulate stand-level variables that were related to the conceptual model either as important abiotic influences on ecosystem structure or function, or as morphological expressions of inputs from the biotic components of the ecosystem.

Continuous numeric variables with biological significance were most useful in exploratory data analyses and statistical comparisons. Non-numeric field records were therefore coded as numeric variables prior to analysis. Where possible, soil characteristics that were recorded in the field as nominal variables were converted to continuous variables. Textural class designations were changed to numeric codes to correspond with the centroid of the class as shown on the soil textural triangle. For example, the texture loamy sand was coded as 17, a value representing the average percent of silt and clay size particles for that soil texture class. Ordinal variables were often more useful in data analyses than nominal variables, so those variables that could not reasonably be converted to continuous variables were sometimes coded along ordinal scales. Physiographic codes, drainage classes, consistencies, and structures, were all given ordinal numeric codes corresponding with the range in their field codes. For example, drainage classes were coded as 1 if the site had excessively drained soils, and 7 if the soils were very poorly drained; other drainage classes ranged between 1 and 7. Continuous variables, such as pH, or depth to low-chroma mottles, were entered as the field-recorded value. Data for each variable at the four subplots were summarized to characterize the sample stand.

Within-stand soil variation presented a special problem in developing stand-level summaries. Soils were particularly variable within stands on morainal and ice-contact landforms; it was not uncommon to encounter distinctly different soil series at each of the four subplots. These differences, mostly due to the amount of textural banding, were caused by fine-scale glacial events that brought flow till or ice-rafted drift to one location and not to another. Because the differences were not reflected in the forest vegetation, we concluded that the depth and lateral extent of tree roots allowed them to intercept the fine-textured material and make use of the greater supply of water and nutrients available there. We often observed fine root proliferation at the boundaries of deep-lying textural bands. Additionally, the cycling of soil nutrients through litterfall was thought to distribute nutrient supplies in the upper soil evenly throughout the stand. Thus, we believed that the soils of the stand as a whole often had a greater nutrient and moisture supply than was evidenced by an individual observation. As we developed the stand-level summaries, if three of the subplots had banding and the fourth did not, we averaged BIC values for the three to arrive at a stand-level value.

DATA ANALYSIS

Data analysis consists of three distinct phases: exploratory data analysis, multivariate analyses and hypothesis testing. Exploratory data analysis involves tests of normality, calculation of simple descriptive statistics, and various graphical methods that allow a "first look" at the data. Graphic representations of the data may reveal trends and interactions that are difficult to extract from the raw numbers. Multivariate methods, such as classification and ordination, are used to characterize correlations and patterns within multivariate data sets. Several multivariate methods, such as two-way indicator species and canonical correspondence analysis (Hill 1979, Ter Braak 1987), have been developed specifically for ecological applications. Hypothesis testing methods may be used to assess ecosystem-level differences in biomass production (Host *et al.* 1988), successional pathways (Host *et al.* 1987), nutrient dynamics (Zak *et al.* 1986, 1989), and other ecological processes. Hypothesis testing is the focus of many statistical texts and will not be considered here.

Exploratory Data Analysis

Exploratory data analysis (EDA) was conducted after field data had been compiled, checked, and verified. We used box-and-whisker plots (Tukey 1977) to look at the average and extreme values of each variable. This graphical method was used to detect outliers - stands with abnormal values - and to inspect the distributions of each variable. Plots were constructed for each variable using the entire data set and for the individual strata. Because our focus was to characterize the stand, we generated stand-level means from the subplot data. Stand averages are also more likely to be normally distributed. Data were tested for normality, and non-normal data were transformed prior to calculating descriptive statistics.

Another simple graphical technique was to plot all possible pairs of variables (X-Y plots). These plots were used to detect linear, log-linear, and curvilinear relationships between the variables,

and to isolate and identify outliers. If two variables within the same data component (e.g. soils) had a high linear association, one could be dropped from future analysis. Pairwise plots are not highly sophisticated and do require time to print and evaluate (for p variables, there are {p-1}p/2 plots), but they provide valuable information on relationships among variables.

Descriptive Statistics and Stand Summaries

After EDA, stand summaries were calculated for each data component. Overstory stand and stock tables (net cubic foot volume) for the Manistee National Forest, shown in Appendix B, were constructed using Hahn's (1984) species-specific regression coefficients for the Lake States. Ground-flora cover-abundance, rank cover abundance, frequency, and importance values were summarized at the stand level (Host 1987).

Stand averages were used to calculate descriptive statistics including means, mean standard errors, and confidence intervals for each stratum, and to calculate the overall weighted mean and variance for the population.

Multivariate Analysis

Multivariate analysis (MVA) was used to identify patterns in species distributions and associations among soil, vegetation, and physiographic variables. Results of these analyses were used extensively for developing the Manistee EC&I. Multivariate methods consider the entire set of variables to better understand their underlying structure. Several multivariate procedures produce graphical representations of the data, which may reveal overall trends and interactions. MVA can be used to reduce dimensionality of the data (principal component, principal coordinate, correspondence, and detrended correspondence analysis), classify the data into groups (divisive classification, cluster analysis), examine the relationships between two or more data sets (canonical correlation, canonical correspondence analysis), or examine the relationship between known groups and the measured variables (discriminant analysis). The sections that follow will briefly describe the nature and uses of several common multivariate methods relevant to ecological land classification, as well as some techniques developed for specific data types.

Ordination

Ordination is one of the primary methods for the multivariate analysis of ecological data. Ordination attempts to arrange the sample plots in a sequence that reflects underlying environmental gradients. Ordination has been a primary tool of ecologists for understanding relationships between changes in species composition and the environment. Austin and Orloci (1966), Gauch and Whittaker (1972), Gauch *et al.* (1977) and others have compared alternative ordination methods. Beals (1973), Ihm and Van Groenewoud (1975), Nichols (1977), Austin (1980) and Wartenberg *et al.* (1987) have examined the assumptions or procedures used in ordination. The following sections describe several ordination methods relevant to ecological land classification.

Principal component analysis.—Principal component analysis (PCA) is the oldest and probably most widely used method for characterizing variability within a multivariate data set; most other ordination methods are variations of PCA. It does not require that the data have a multivariate normal distribution. PCA of overstory (density, volume, age, etc.) or soil characteristics may help evaluate the internal variability of the data, detect outliers, and produce stand ordinations. PCA creates linear combinations of the original data in such a way that the total variability of the data set is concentrated into the first few new combinations. The linear combinations, or principal components, are linearly independent. It is, therefore, possible to calculate the relative amount of the total variation explained by each principal component by examining its variance (i.e. the eigen roots). If the first three to four principal components explain 80 percent to 90 percent of the total variability in the data, they can be used to summarize and plot the data with little loss of detail.

If the strata sampled are homogeneous and unique, plots of the first few principal components should show the strata as distinct subgroups. The influence of each variable on the principal components, and therefore on the total variability of the data, may be determined from the size and magnitude of the coefficients used to calculate the principal components.

Typically, the variables used for PCA will have several different scales and units. In such cases,

it is suggested that principal components be done using the correlation rather than covariance matrix. This has some drawbacks because correlation is data driven, highly susceptible to outliers and sample size, and it ignores nonlinear relationships. For this reason, some analysts prefer to use log-transformations and the covariance matrix for PCA when the data are in different units. In the Manistee National Forest EC&I, PCA was used extensively to analyze soils data; these methods will be discussed in a later section.

An excellent reference on principal component analysis is *Principal Components Analysis* (Jolliffe 1986). Other good texts are *Multivariate Analysis of Ecological Communities* (Digby and Kempton 1987) and *The Interpretation of Ecological Data* (Pielou 1984).

Principal coordinate analysis.—Unlike principal component analysis, a second ordination method—principal coordinate analysis—does not require continuous or ordinal data (Gower 1966). Principal coordinate analysis (PCO) operates on an association matrix between the individual sites. New coordinates for the stands are created by spectral decomposition of the association matrix. The end result of PCO is a graph in which the interpoint distances approximate the similarities (or dissimilarities) between corresponding pairs of sites (Gordon 1981). Similar stands should be relatively close together on the plot; very different stands should be far apart.

The power of PCO is that the association matrix may be composed of any measure of dissimilarity. For binary data, the simple matching coefficient or Jaccard's coefficient may be used to construct the association matrix. If the data are interval/scale data, then Euclidean distance, Mahalanobis distance, or Canaberra distance metrics may be used. If the data are a combination of interval, discrete, and binary data, the different association matrices may be combined into a weighted average for analysis. This combined index, Gower's index, is discussed in Digby and Kempton (1987).

Soils data in particular may contain a mixture of variable types. The data set for the Manistee National Forest, for example, contained both ordinal and continuous data. The association matrix for the stands could be formed using a Pythagorean metric for the quantitative variates and a city-block (Manhattan) metric for the ordinal variates. If the first two or so dimensions account for most of the variability in the data, groups of similar stands can be delineated from a relatively simple (two- or three-dimensional) graph.

Detrended correspondence analysis.—Detrended correspondence analysis (DCA), and its precursor, correspondence analysis (CA), were developed to analyze counts or measures of species abundance. DCA or CA may be used to analyze the ground flora (frequency, abundance) and the overstory (trees/acre) species. The end product of these methods is an ordination of species or samples, commonly expressed as an ordination space diagram (fig. 2). The data matrix, X, would contain counts or abundance measures of different species (columns) across the stands (rows) sampled. A singular value decomposition of the centered X matrix creates row and column scores for the data; there is one set of scores for the individual species and one set of scores for the stands (Liebert *et al.* 1984). When graphed, the species scores reflect the relative positions of individual species across all stands in response to one or more environmental gradients (fig. 2). The relationship of species composition to environmental gradients may be tested statistically using canonical correspondence analysis, described below. Stand scores can be used to produce another ordination, with similar stands plotting close together and dissimilar stands plotting far apart.

If the strata sampled represent unique ecosystems, then correspondence analysis should reveal the strata as distinct or overlapping zones along the gradient (fig. 2). The plot of the species will show which species or species group is most representative of an individual stratum.

Although these methods were developed for count data, other measures of abundance or frequency may be used. A good reference to correspondence analysis is *Theory and Application of Correspondence Analysis* (Greenacre 1984).

Ordination comparisons.—Several examples have been given to illustrate the application of different multivariate methods. The methods used—DCA, PCA, and PCO—produced stand ordinations for different data components. Understory and overstory abundance data were

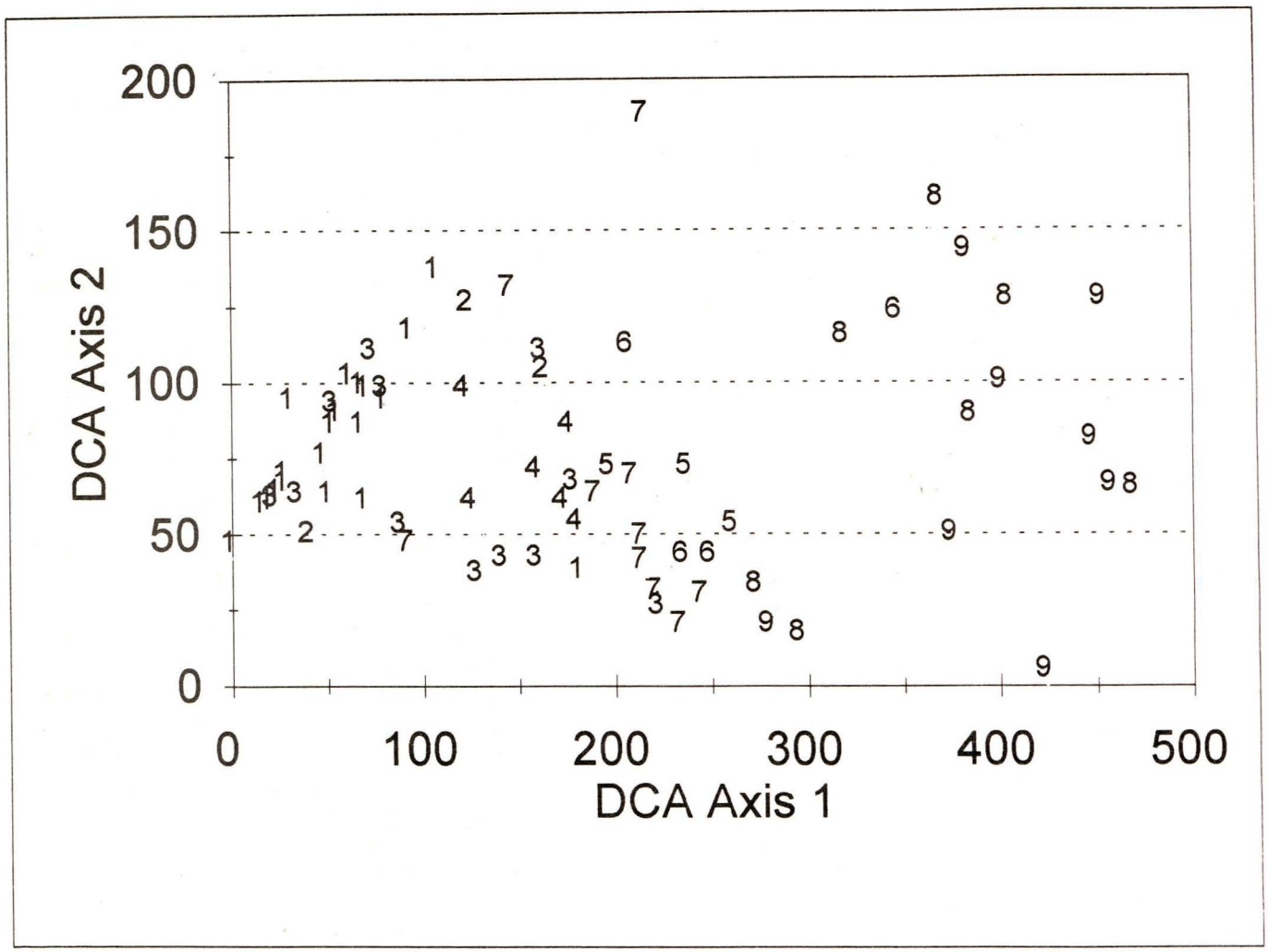

Figure 2.—*Detrended correspondence analysis of Manistee National Forest EC&I stands based on overstory basal area. Values represent the following landform codes: (1) outwash plains; (2) Valparaiso-Charlotte moraine (unbanded); (3) ice-contact hills; (4) Port Huron moraine (unbanded); (5) Valparaiso-Charlotte moraine (banded); (6) Port Huron moraine (banded); (7) ice-contact hills (banded); (8) Interlobate moraine (unbanded); (9) Interlobate moraine (banded). Adapted from Host* et al. *(1992).*

analyzed with DCA, soils data with PCO and PCA, and stand characteristics with PCA. Obviously, researchers would like to compare all ordinations to see if they agree or how much they disagree.

Different methods have been used to relate ordinations to environmental factors or to other ordinations. A common approach has been to use simple or rank correlation of ordination scores to compare separate vegetation layers (Peet and Loucks 1977, Robertson 1978, del Moral and Watson 1978, McCune and Antos 1981) or to relate ordination scores to environmental variables (Dyrness and Grigal 1979, Westman 1980, Rodgers 1981, Carleton 1984).

Because interpoint distances are not independent, however, simple correlations may not be legitimate (Gower 1971). Several methods are available that allow comparison between ordinations.

Standard Procrustes rotation.—Procrustes rotation, first discussed by Hurley and Cattell (1962), may be used to compare two ordinations. One configuration is held fixed, and the second configuration is rotated and scaled to fit the first. Because both configurations are already centered, the ordinations should be scaled, but not centered before Procrustes rotation.

If both ordinations reflect the same or similar environmental gradients, the stand configuration obtained from an ordination of the ground flora should be similar to the configuration obtained from an ordination of the overstory density. Procrustes rotation can be summarized in an analysis of variance table. Sums of squares and the residual sums of squares around the common centroid are calculated for each ordination. Sums of squared distances between sites in the two ordinations are the residual sums of squares. If the two ordinations agree, then the residual sums of squares should be quite low, compared to the ordination sums of squares.

Procrustes rotation also provides a rotational matrix, which shows how the original axes of the second configuration are rotated to fit the first configuration. If the two configurations were obtained by different methods, such as PCO and CA, then they should be scaled during rotation. The scaling factor is determined through least squares, and provides another clue to how well the ordinations agree. One way to make the residual sums of squares as low as possible for two quite divergent ordinations is to greatly reduce their scales. As both ordinations are shrunk towards the centroid, their sums of squares are reduced, which in turn reduces the residual sums of squares. Procrustes rotation can be easily programmed in any matrix language for a microcomputer.

Generalized Procrustes analysis.—Procrustes rotation could be used to examine all pairwise comparisons between the three ordinations produced. This could be done for detrended correspondence analysis of the ground flora, correspondence analysis of the overstory, and principal coordinate analysis of the soil variates. A basic premise of the classification system is that all site factors contribute to the final ecological identification of the site. Reliance on only one component—soil or vegetation—ignores other factors that influence or characterize the site, and may therefore produce a less than complete classification. Another method, Generalized Procrustes analysis, may be more appropriate for identifying patterns among multiple data sets.

In ordination, the interrelationships among the stands are displayed as distances between the points; similar stands are represented by close points and visa versa. The properties of distance remain unchanged if the points are translated to a different origin, if the points are rotated to a new set of axes, or if the ordination is scaled by an arbitrary (non-zero) constant (Krzanowski 1988).

When comparing ordinations, we are interested in the internal relationships for the n points between the ordinations. Generalized Procrustes analysis (Gower 1975) can be used to obtain an overall, or consensus, ordination of the stands from the two or more ordinations. This method simultaneously translates, rotates, and optionally scales the original ordinations in all dimensions so that they match, as closely as possible, a consensus ordination.

Generalized Procrustes analysis involves all dimensions of each ordination. To illustrate, an ordination from a detrended correspondence analysis of ground flora could be represented by 43 dimensions, the correspondence analysis of the overstory could produce an ordination with 12 dimensions, and the principal coordinate analysis of the soil could have 38 dimensions. Generalized Procrustes analysis uses all dimensions from all ordinations to define the consensus. This has obvious advantages over one-dimensional comparisons, such as in correlating first dimensional scores from each pair of ordinations.

Goodness of fit can be assessed for each original ordination from its residual sums of squares, i.e., the sum of squared distances of its points (after translation, rotation, and scaling) to the corresponding points in the consensus ordination. Individual stands that are not represented similarly (i.e. mapped to the same space) in the original ordinations may be identified by their relatively large residual sums of squares. The

residual distances are defined relative to each individual stand. The residual distance for stand z, for example, would be the sums of the distances from stand z in each configuration to the centroid of the points.

As with standard Procrustes rotation, additional information is provided by the rotation matrices from each configuration. The directional cosines (see Digby and Kempton 1987) show the direction of rotation of the old axes (columns) with respect to the new axes (rows) to produce the consensus. A negative sign for a directional cosine shows that it was reflected before rotation.

Canonical correspondence analysis.—Canonical correspondence analysis (CCA) provides an alternative means of comparing ordinations, with an added advantage of determining the proportion of variance in community structure that may be accounted for by an environmental data matrix. This relatively new multivariate technique combines the direct gradient analysis method of multiple regression with the indirect gradient analyses from ordination methods (Ter Braak 1987). The result is an ordination whose axes are a linear combination of a supplied set of environmental variables. CCA can be used for both exploratory data analysis and for hypothesis testing. In its exploratory sense, the ordination will optimally display how community composition is related to environmental variables. It not only assesses how variation in community composition is related to environmental variation, but also allows ordinations to be "constrained" (analogous to analysis of covariance) to allow secondary and tertiary environmental matrices to be analyzed.

In the hypothesis testing sense, CCA will produce statistical tests of the effects of particular environmental variables, taking into account the effect of other variables (Ter Braak and Prentice 1988). For EC&I development, this analysis is particularly suited for testing relationships between ground-flora compositional data and soil or other environmental data and for quantifying the strength and statistical significance of these relationships.

Canonical Correlation

Canonical correlation (CC) is used to discover relationships among variables within two distinct sets of data. Multiple regression attempts to find linear combinations of the data set [X1, X2, X3...Xp] to explain the natural variability in Y. CC is used when there is a set of predictor variables [X1, X2, X3...Xp] and a set of outcome variables [Y1, Y2, Y3...Yq]. CC, which has rather formidable data requirements (see Gittins 1985), calculates canonical correlations between linear combinations of the X's (Uj) and of the Y's (Vj). The first pair of new canonical variates (U1, V1) will have the largest correlation of all possible linear combinations. The second pair (U2, V2) will have the second largest correlation, and so on. All other correlations between the canonical variates are zero. The canonical correlations can be tested for significance, to determine if linear relationships do exist between the two sets of data.

Relationships between the set [X] and [Y] are based on the canonical variates. Examining the canonical weights, canonical loadings, and the correlations between the canonical variates and the original variables will help determine which of the original variables are important to the relationship.

CC could be used to relate soil and site factors (predictors) to stand productivity (outcome). If the first canonical correlation is significant, the loadings will show which soil variables help explain the variability in the overstory. The variables selected for CC may influence the results; in particular, collinearity among variables will cause instability of the canonical weights. Collinearity may be detected and corrected using methods discussed by Gittins (1985; p. 262).

Redundancy analysis (Cooley and Lohnes 1971) is a valuable option to determine the importance of the pairs of canonical variates. Redundancy analysis looks at the amount of variability within each data set explained by a canonical variate. Linear combinations that explain only a small percentage of the total variation should be ignored, even if their canonical correlation is significant.

Multivariate Methods for Developing Ecological Species Groups

The ability to incorporate ground flora into multifactor land classification systems is facilitated by the use of *ecological species groups*:

groups of species with similar patterns of constancy and fidelity across a regional landscape (Mueller-Dombois and Ellenberg 1974). Constancy refers to the degree to which a species occurs within a given range of environmental conditions; fidelity refers to the degree to which a species is restricted to that range of conditions. Species with both high constancy and high fidelity provide good indicators of site conditions: they are often encountered in their characteristic landscape positions and rarely occur outside these specific environments. The use of groups of species avoids problems because of the chance presence or absence of individual indicator species, and capitalizes on the ecological information available by involving a significant proportion of the existing community. The objectives of an analysis of vegetation data are to:

1) identify the ecological amplitudes of species encountered in field sampling

2) relate species distribution patterns to significant environmental variables

3) identify ecological species groups

4) integrate discriminatory ecological species groups with the other biotic and abiotic components of the classification.

Ecological species groups have historically been formed using releves (species lists ordered by sampling quadrants), tabular analyses, and more recently by various multivariate numerical methods (Mueller-Dombois and Ellenberg 1974, Gauch 1982, Spies and Barnes 1985b, Host and Pregitzer 1991). Multivariate methods include agglomerative and divisive clustering, and ordination based on principal component analysis or its many variants. All these techniques have been used with varying degrees of success, and each has advantages and disadvantages. The tabular arrangement or releve methods require a good understanding of species/site relationships and are inherently subjective. Agglomerative classification methods (which begin with all stands treated separately and join or fuse stands based on similarities in composition) tend to be sensitive to "bad" fusions in the initial stages of clustering if atypical samples are present (Pielou 1984). Spies and Barnes (1985b) found agglomerative clustering to be unsuccessful for forming species groups for the Sylvania Recreation Area, and suggested the use of two-way indicator species analysis (TWINSPAN), a polythetic divisive classification method (Hill 1979). TWINSPAN is designed to construct ordered species-by-sample tables (also known as synthesis tables) based on differential or indicator species. Synthesis tables are a mathematically derived equivalent of the vegetation tables used by Spies and Barnes (1985b). TWINSPAN may also be used to identify ground-flora species that are important in discriminating different levels of classification. Thus, this technique is one of the more important tools for integrating floristic data into the classification system.

A second approach to numerical development of species groups is the ordination of species followed by partitioning of ordination space (Gauch 1982). Ordination refers to a logical "ordering" of species (or stands) along a compositional gradient. A fundamental assumption behind this method is that the species compositional gradient reflects some underlying environmental gradient that controls species distribution patterns. This is, in essence, indirect gradient analysis as described by Whittaker (1967). Ordination space partitioning is performed by constructing a two-dimensional ordination of species and by drawing partitions through sparse regions of the cloud of sample points. These partitions should complement results from classification and cluster analyses.

Although PCA is very effective for analyzing typical multivariate data sets, the analysis of vegetation data presents some unique problems. A vegetation data matrix generally consists of some measure of species importance, such as coverage, frequency, or importance values arranged by species and stands. For reasons inherent to the mathematics of the technique, the high proportion of zeros in a typical floristic data matrix tend to distort the second and subsequent principal axes; this distortion is commonly referred to as the "arch effect." Detrended correspondence analysis (Hill and Gauch 1980) avoids the problems of the "arch effect" and axis compression that occur when principal component analysis or correspondence analysis are used with vegetation data (Hill 1979). In spite of some recent criticism of this technique, DCA remains one of the more popular and widely used techniques for analyzing vegetation data (Peet *et al.* 1987).

Although these numerical techniques are in themselves objective, the choice of techniques, the use of weighting coefficients, and the deletion of rare or "noisy" species are subjective decisions. Therefore, numerical methods are not entirely objective, and are not meant to be used blindly as group-generating algorithms. They are, however, extremely valuable at detecting patterns of association based on constancy, fidelity, and abundance in vegetation data, and are important techniques for the construction of ecological species groups. Host and Pregitzer (1991) detail the methods and results from developing ecological species groups on the Manistee National Forest.

Multivariate Methods for Analysis of Soils Data

Many of the techniques used in analysis of overstory and ground-flora data are also applicable to soils data. Soils data, however, present some unique problems. Often, the data are not distributed normally. Because soils data can be summarized in a number of ways, it is possible to extract a very large number of variables. In addition, soils data have a wide range in values, from pH measured at a tenth of a unit, to depths measured in hundreds of units.

Log-transformations of the data will often correct the lack of normality to some degree. Frequency distribution plots of individual variables may be used to determine the shape of the distribution, and the non-parametric Kruskal-Wallis test may be applied to show if samples from different groups belong to the same distribution. Many multivariate statistical procedures require an assumption of normality, and the lack of normality of soils data may preclude their use.

Principal component analyses, as described previously, were especially useful for analyzing soils data because multivariate normality is not required, and continuous or ordinal data may be used. PCA's were used to reduce the dimensionality of soil data sets while retaining most of the information. The principal components, because they are linear combinations of the variables, have sometimes been used in place of the original variables as a smaller data set for further clustering and discriminant analyses (Denton 1985). PCA also identifies variables in the original data set that contain the greatest amount of information, or internal variability among observations, and hence are best for use in predictive models. Then, the least informative variables may be eliminated from further analysis if so desired (Morrison 1976, Broschat 1979). Plots of the first several dimensions will display groupings of similar sample units, and show outliers that may also be dropped from the analysis (Pregitzer and Barnes 1984). Thus, the size of the data set may be reduced by using the principal components as new variables or by dropping less important variables or sites from the analysis.

PCA may be performed on either the correlation matrix or the covariance matrix. The correlation matrix has been used more frequently than the covariance matrix for soils data. PCA's using the covariance matrix will place undue emphasis on variables with large absolute values for means and variances, and so should not be used unless variables have similar scales of measurement. The use of the correlation matrix avoids rather than solves this problem, but is considered satisfactory if all the variables used are of similar importance (Morrison 1976, Chatfield and Collins 1980). It is often difficult to determine if variables are of similar importance; however, with soils data, measurements are frequently made on scales that differ by several orders of magnitude, making use of the covariance matrix more problematic than the question of relative importance.

Examining the coefficients for each variable (also known as weights) permits identification of the variables that are most important or that account for much of the variation among sample sites and would be best for use in additional analyses or in predictive models (Pregitzer and Barnes 1984). Important variables may also be identified by examining the correlations of the variables with the principal components. The variables with the greatest correlations with the first principal component will be the most important, expressing a large amount of variation in that dimension. The variables with high correlations should be the same ones that had the greatest coefficients in the principal components equation.

Correspondence analysis and detrended correspondence analysis were described in a previous section. These techniques may also be applied to soils data, and results will usually be similar to PCA. When CA and DCA are used with soils data, the individual soil variables are assigned the equivalent of species codes in vegetation

analysis. Thus, the sample-by-species ordination common in vegetation analysis becomes a sample-by-soil-variable ordination. The advantage of using these techniques with soils data is that plots of site ordinations may be overlain with plots of soil variable ordinations, to identify those soil variables that influenced the ordination of individual sites.

Linear Discriminant Functions for Assigning Stands to Classification Units

Linear discriminant analysis (LDA) may be an important class of methods to be used after development and validation of an EC&I. LDA's are designed to classify new observations (e.g. unknown forest stands) into an existing classification structure. To illustrate, say that previous methods have led to the definition of 10 unique ecosystems. All sample observations have been assigned to one of the 10 ecosystems, and means and covariances have been calculated. Furthermore, assume that the probability of assigning a new observation to ecosystem 'i' is the same for all 10 ecosystems. Then, with LDA, it is relatively simple to use the variables that define the ecosystems to develop a set of decision rules. As each new observation is measured, its values are plugged into the decision rules, which assign the new observation to one of the 10 ecosystems. The advantages should be clear.

There are several reasons not to use LDA during the initial stages of developing a classification system. First, LDA assumes multivariate normality, which is very difficult to test for in large data sets. Second, LDA assumes that the parent populations (the individual ecosystems) have equal covariance matrices. This assumption may be rejected conceptually, but it should be tested. Unfortunately, the small samples usually associated with EC&I development impede tests for equal covariance. Third, if the samples used to develop the decision rules were incorrectly assigned to the known populations, the decision rules are invalid. This means if a stand is incorrectly labeled as belonging to ecosystem A, when it truly belongs to ecosystem B, then it disrupts the mean vector and covariance matrix for ecosystem A. Because the original populations are erroneously described, any decision rules will be in error. Fourth, a common assumption is that each population has an equal probability of being sampled. If this assumption is violated, the decision rules can be drastically changed.

For these reasons, linear discriminant analysis is recommended for use after the classification has been developed, tested, and verified. Waiting until these steps are accomplished should eliminate errors in classification, allow better estimates of *a priori* probabilities, and result in a larger sample to use for testing multivariate normality and equal covariance matrices.

ECOLOGICAL CLASSIFICATION AND INVENTORY DEVELOPMENT

The Manistee Ecological Classification and Inventory follows the hierarchy proposed by Bailey (1987) and outlined in the Forest Service Manual (FSM 2060). The upper levels of the hierarchy are structured according to climatic and regional physiography. Albert *et al.*'s (1986) climatic and physiographic classification of Michigan, combined with previous geomorphic studies of Michigan (Farrand 1984, Martin 1955), formed a preliminary basis for the primary stratification; this work was augmented by detailed research specifically on the Forest (Cleland *et al.* 1993; Host 1987; Host *et al.* 1988; Host and Pregitzer 1991, 1992; Zak *et al.* 1986). Lower levels of the hierarchy were structured using (1) local geomophology in conjunction with mesoclimatic gradients (Landtype Associations), and (2) local soil and physiography in conjunction with floristic patterns (Ecological Landtype Phases).

Landtype Associations

Albert *et al.* (1986) stratified the Manistee National Forest into four climatic/physiographic districts or subdistricts. They recognized that the climatic transition from the lake effect zone of Lake Michigan to the interior highlands is quite gradual, making it difficult to determine exactly where delineations should be placed. Climatic boundaries were therefore placed along physiographic features such as moraines and major drainages.

We felt that the land managers on the Manistee National Forest needed information at a finer scale than that provided by the Albert *et al.* (1986) stratification. Therefore, the Subsection level of the classification hierarchy, as described by Bailey (1987), was developed based on subdivisions of Albert *et al.*'s (1986) map of Regional Landscape Ecosystems. Division of the units

was based on climatic and physiographic differences that did not differentiate among areas at the larger scale. Subsection level classification units are described, and the basis of their development is discussed, in the Huron-Manistee National Forests' field guide (Cleland *et al.* 1993).

Landtype Associations (LTA's) were originally developed in the mid-1980's for use in developing the National Forests' Land and Resource Management Plan. The task was accomplished by photointerpretation of aerial photos at the 1 inch=1 mile scale, delineating along physiographic formations. These original LTA's were not nested into the upper hierarchical levels of the classification system at that time.

The landscape of northwest Lower Michigan is geomorphically complex, resulting from initial glacial deposition modified by subsequent large-scale erosional events. Host *et al.* (1988) identify two distinct ice-edge positions occurring NE-SW across the Manistee National Forest. The resulting landforms are characterized by extensive moraines and isolated sets of ice-contact hills in an extensive matrix of outwash sands. Based on differences in geomorphology and its effect on vegetation, we nested the original LTA's into the Subsection classification, and defined them individually for each Subsection. The result of these combined analyses, at the Subsection and LTA levels, was a set of ecological types tailored to the climate and physiography of northwestern Lower Michigan, at various scales used in different levels of planning and management on the National Forest. Subsections and LTA's are described in the field guide (Cleland *et al.* 1993).

Climatic and geomorphic analyses are critical in developing a hierarchical classification. In many cases, previous research and inventories may provide a strong and possibly complete basis for identifying and defining the Subsection and LTA levels of the classification. Persons working on ecological land classifications should evaluate and apply existing regional-scale information. New research can then be directed toward gathering additional information to more fully delineate and describe LTA's for specific National Forests.

Ecological Landtype Phases

Within the LTA level of stratification, Ecological Landtypes (ELT's) or Ecological Landtype Phases (ELTP's) are defined by integrating physiographic, floristic, and edaphic data obtained through field sampling. Because each of the ecosystem components is characterized by many variables (e.g. individual ground-flora species, numerous soil and physiographic measurements), the synthesized groups produced through the multivariate analyses described earlier (e.g. ecological species groups or dominant PCA axes based on soils variates) provide an interpretable quantification of the degree and nature of variation in each ecosystem component. Although the simple crosstabulation or factorial approach based on ecosystem components (i.e. all species groups crossed with all edaphic classes) may be used in identifying ELTP's, we have found that this approach produces a large number of ecologically unrealistic units. The most workable and functionally interpretable ELTP's are formed by the development team and experts in respective ecological disciplines working together to interpret and integrate the components based on knowledge, experience, and interpretations of the univariate and multivariate analysis of the data. This human element in the classification, while arguably subjective, allows incorporation of insights relevant to forest classification and management that may not be evident in data analysis (Wickware and Cowell 1985). Although the statistical methods described above are essential for handling the volumes of different types of ecological data generated in these studies, they are not sufficient to develop ecological land units ready for use in a management setting.

ELTP's on the Manistee National Forest were developed by integrating the ecological species groups with selected soil variables (primarily soil texture, B horizon development, and the presence, absence, or degree of textural banding or subirrigation present within the upper 4.5 m) in association with local physiographic conditions (slope and aspect). ELT's were developed by combining ELTP's with similar ecological species groups, soil moisture and nutrient status, and overstory composition.

By identifying relationships between ground-flora composition and soil variables, we are able to simplify the field mapping process. Presence of the *Osmorhiza* ecological species group, for example, has been found to be consistently associated with the presence of soil textural banding. Thus, when this group is present, there

is no need to auger to detect the presence of bands. The *Maianthemum* group, on the other hand, occurs on both banded and unbanded sites; and augering to detect banding is still needed to determine the ELTP.

Methods for EC&I Validation

The Manistee EC&I has been validated through field application and inventory. It has not yet been validated, however, through collection of an independent data set within the study area, data interrogation, and comparison of results to initial analyses. Collecting additional data and conducting additional analyses is the most objective means of verifying a classification system. This method of validation is desirable from a research perspective, and should be conducted as part of continued EC&I development and refinement.

A classification system should repeat several cycles in its development, testing, and refinement before being adapted for use. Measures of accuracy and goodness of fit are quite optimistic when based on the data used for model development (Mosteller and Tukey 1977). Therefore, model validation is more acceptable when performed on an independent data set. Alternatively, when the sample is quite large, a small portion of the data may be withdrawn from model development for eventual use in model testing. The data withdrawn become the independent data set.

An ecological classification system, however, is not a predictive model in the sense of producing a single estimate based on input values. Therefore, the battery of procedures available for testing predictive models (Picard and Cook 1984, Reynolds 1984) and for nonparametric estimates of prediction error (Schreuder and Anderson 1984) cannot be applied. Still, the idea that the modelers should attempt to "...derive an expression for the maximum anticipated error...that might result when the model is used for predictive purposes" (Reynolds 1984) has real merit.

Spies and Barnes (1985a) used discriminant analysis to evaluate the "distinctness" of 25 ecosystems in Michigan's Upper Peninsula. They did not test the robustness of the ecosystem classes, but instead evaluated the discriminating strengths of the different ecosystem components. Once the integrity of the ecological classes has been tested, and if assumptions of multivariate normality and equal covariance matrices are met, then discriminant analysis is recommended.

Arno *et al.* (1986) suggested two procedures for testing and refining a successional classification for western Montana. The first consisted of a "second approximation," essentially enlarging the sample and repeating the analysis. The second consisted of field tests by an independent investigator.

The procedures recommended in this section focus on testing the integrity and robustness of the ecological classes. One procedure uses the original data set; the other two require additional field sampling and are similar to the procedures suggested by Arno *et al.* (1986).

A. Test robustness of the original classification by using the original data and a procedure similar to cross-validation. The intent is to determine if the classification is dependent upon any individual sample unit or subset of sample units.

   1. Cross-validation in modeling is data-intensive, but relatively simple. Leaving out one data point at a time, the model is fit to the remaining points and then used to predict the excluded point. The average of predicted errors for all n points, leaving out one at a time, is the cross-validated measure of predicted error (Efron and Gong 1983).

   2. As mentioned above, the EC&I does not predict a single value with an associated predicted error. Therefore, a method similar to cross-validation is suggested, realizing that it will produce only a subjective test of robustness. A random subset (one or more stands) of the original data is removed from the data set. The procedures used to develop the ecological classification (e.g. principal component, two-way indicator species, and detrended correspondence analysis) are repeated on the reduced data set to produce new ecological classes. The process is then repeated with a new random subset being removed.

   3. If the ecological types change due to elimination of one or more samples, then the classification should be challenged. If

the original classification was robust, and is not sensitive to specific sample units (stands) being present, the "new" ecological classes should be quite similar to the original ones. This is a more time-intensive process than cross-validation for modeling because several procedures are used to develop ecological species groups and ecological classes.

4. Procrustes analysis (Digby and Kempton 1987) may be used to compare multidimensional ordinations from correspondence analysis or other ordination methods.

B. Apply the original classification procedures to an expanded data set. Given the relatively small sample used to develop the Manistee classification system, we strongly recommend this step.

   1. The intent is to take additional samples in each of the sample strata (ecological classes). Stands not selected for the original sample from the strata sample frames may be used if the original strata are still intact (i.e. the strata have not changed as a result of the classification).

   2. The new samples are combined with the original data set, and the analytical procedures used to construct the classification system are applied to the expanded data set. The resulting classes are then compared to the old system to see if the original ecological species groups, overstory groups, etc., have been recovered.

   3. The classification system is then modified as necessary, based on the new analysis. These steps are then repeated; the classification system should be in a continuous state of refinement by testing.

C. Test mapping accuracy in the field. Landform, ecological species groups, and soil characteristics are used to define the ecological units in field mapping (Spurr and Barnes 1980). Once mapping has begun, select stands at random from the mapped areas to test the accuracy of the classification system. This is really a combination of testing the ecological classification system developed and testing the mapping procedures.

   1. Stands are sampled at random, within each ecological type, from areas mapped using the ecological classification system. Information is collected by intensively sampling vegetation (overstory, understory, ground), productivity, and soil characteristics. The field procedures are the same as those used to collect the original data for classification development.

   2. Mean stand values for the individual variables in each component are compared to the means developed from the original classification. If the data can be considered multivariate normal, then Hotelling's T^2 statistic can be used to comparethe means of each component (soil, overstory, understory, ground vegetation) from each stratum to the hypothetical population means—the mean values derived from the original data set.

   3. Significant differences between the vectors of means may be due to errors in mapping or classification. The source of the differences must be determined, and mapping procedures or the classification system must be corrected.

EC&I Field Guide and Key Development

A field guide and key that contains all the information necessary for field personnel to use the classification system should be developed. The field guide should describe the hierarchical structure of the classification, present maps of at least the upper hierarchical units, and provide descriptions, characterizations, and interpretations for each of the ELTP's identified. It should also include a key, so that unmapped units may be identified in the field. A well-constructed key should reflect the hierarchical nature of the classification; it should begin with those features that key to the LTA level and finish with characteristics that identify individual ELTP's. The key should be supplemented with supporting information, such as plant illustrations, descriptions of soil variables and characteristic soil horizons, and definitions of the various ecosystem attributes. The field guide can be prepared both in a loose-leaf format as well as in digital, hypertext format. The hypertext format has the advantage of being readily updated, easily distributed, and

able to be linked with extensive supporting data bases and forest/wildlife management expert systems (Rauscher and Host 1990). The field guide for the Huron-Manistee National Forests is available from the Huron-Manistee National Forest. A hypertext version is under development (Rauscher and Hacker 1989).

EC&I Information Management

To date, paper maps and relational data bases have been the primary tools for managing EC&I information. Such information is inherently spatial in nature, and the cartographic units produced in the mapping process contain information on the means and variances of several ecosystem attributes. These types of spatial data bases are well suited to manipulation and analysis with Geographic Information Systems (GIS). GIS provide a means to link multiple relational data bases to the physical map units, allowing complex analyses to be conducted. For example, a GIS data base can be queried to produce a map of all northern hardwood stands of a particular slope and drainage within one-fifth mile of a river and one-half mile of improved road for locating potential recreation sites. Such analytical capabilities are important for both strategic and tactical forest planning.

Because ground flora is an essential part of the classification, GIS allows information on the availability of vegetation important to wildlife management or maintenance of biotic diversity to be placed in a cartographic framework. Understanding the spatial relationships of ecological land units at various scales has important implications for developing landscape design strategies (Johnson *et al.* 1991). Although GIS methods have been available for some time, ecologists and land management agencies have been slow to utilize the descriptive and analytical powers of GIS (Johnson 1990). The spatial nature and multifactor information contained in ecological land classification make the combination of EC&I and GIS technologies a primary forest management tool for the coming decades.

SUMMARY

The Ecological Classification and Inventory of the Manistee National Forest was developed by stratifying the landscape to identify climatic and regional physiographic units, and then by intensively sampling the salient ecological components: overstory, ground flora, and surficial and deep soils. Univariate and multivariate analyses were used to examine the underlying variance structure of the individual data sets as well as correlations within and among these data sets. Classification and ordination procedures were used to group stands of similar floristic composition and soil properties. Ecological species groups were identified. These groups of stands became preliminary ecological types, which were further refined through continued analysis and field test mapping. Input from research scientists, field foresters, and forest management personnel was critical in developing classification units. Each ecological unit was described and interpreted; and a comprehensive field guide was developed. Ecological units were validated by conducting jackknife procedures on existing data, classifying new samples, and field testing mapping accuracy.

This sampling and analysis protocol can be generally applied across forests of Eastern North America; specifics of the sampling design and variables measured will likely change across macroclimatic and physiographic boundaries. In all cases, however, highly accurate field sampling, care in data management and analysis, the combined experience of a multidisciplinary development team, and ongoing validation and refinement process are needed to ensure a robust and effective ecological classification.

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APPENDIX A

EXAMPLE FIELD DATA SHEETS

Site Description

HURON-MANISTEE
ECOLOGICAL CLASSIFICATION SYSTEM

STAND 8

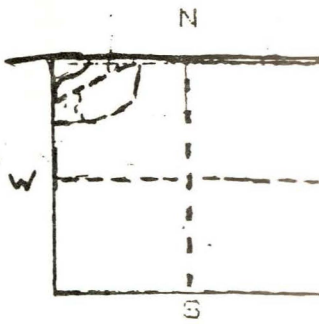
********** MASTER PLOT DOCUMENTATION & CHECKLIST dmm 6.17.83***

DATE LOCATED 6/27/83 CREW GH DZ, SN RECORDER _____

STRATA ID
REMARKS BLACK 7

TSP 22N. RGE 13W. SECT 28 N___ W___.

Co. MAN. FOREST ____. DIST _____



LOCATION (REFER TO SECTION DIAGRAM) N1/4 NW1/4 Sec. 28
.5 MILES E OF BRETHEREN ON COATES HWY 2.8 MILES
.5 ON FS 5484. STAKE BY RED OAK 12" DOH
75' at 171 AZ 75' at 140 AZ 300' at 164 AZ
75' at 172 AZ 75' at 178 AZ 63' at 175 AZ

********** FORMS COMPLETED **********
(INDICATE F FOR FLD CKD AND/OR FOR ALL COMPLETE)

✓ TOPOGRAPHY/GEOLOGY/LANDFORM ___ SOIL PIT DATA ✓ AUGER HOLE SOIL

✓ SI DATA ___ SOIL SAMPLING DATA

___ PRODUCTIVITY DATA ✓ FLORISTICS DATA

********** ACTIVITIES COMPLETED **********

✓ STAKES PLACED.

___ LOCATED ON TOPO SHEET _____.

___ LOCATED ON PHOTO # _____.

___ PHOTOS TAKEN. (PHOTO #, DATE, CAMERA, PHOTOGRAPHER, f#, SPEED, BRIEF DESCRIP. OF SUBJ. & LOCATION)

1. _____
2. _____
3. _____
4. _____
5. _____
6. _____
7. _____

PRODUCTIVITY DATA SHEET: ECS INVENTORY

Stand xx BAF xx Date xx/xx/xx / /87

Point number xxx Recorder

Direction from soil pit Distance from soil pit ch.

Tree No.	Species	dbh	total ht	merch ht	crown ratio	crown class	10-yr growth	age @ dbh	site index
xx	xx	xx.x	xxx	xxx	x	x	x.x	xxx	xx
1		.					.		
2		.					.		
3		.					.		
4		.					.		
5		.					.		
6		.					.		
7		.					.		
8		.					.		
9		.					.		
10		.					.		
11		.					.		
12		.					.		
13		.					.		
14		.					.		
15		.					.		
16		.					.		
17		.					.		
18		.					.		
19		.					.		
20		.					.		
21		.					.		
22		.					.		
23		.					.		
24		.					.		
25		.					.		

Total BA/acre: Merch. BA/acre (>3.5"):

Comments:

ECS PRODUCTIVITY SAMPLING

Field Procedures for Summer 1986
Codes for Productivity Tally Sheet

A. Crown class: use the following codes -

1: open grown, isolated
2: dominant (light from above, sides)
3: codominant (light only from above)
4: intermediate
5: suppressed or overtopped

B. Crown ratio: use the following codes

1: live crown <= 10% of total tree height
2: 11% < crown ratio <= 20%
3: 21% < crown ratio <= 30%
4: 31% < crown ratio <= 40%
5: 41% < crown ratio <= 50%
6: 51% < crown ratio <= 60%
7: 61% < crown ratio <= 70%
8: 71% < crown ratio <= 80%
9: 81% < crown ratio <= 90%
0: used to code missing data

C. Species codes:

01 Jack Pine
02 Red Pine
03 White Pine
04 White Spruce
05 Balsam Fir
06 Black Spruce
07 Tamarack
08 N. White Cedar
09 Hemlock
10 Other softwoods
11 Black Ash
12 Cottonwood
13 Silver Maple
14 Red Maple
15 Elm (all)
16 Yellow Birch
17 Basswood
18 Hard Maples
19 White Ash
20 White Oak
21 N. Red Oak
22 Black, Pin Oaks *
23 Hickory spp.
24 Bigtooth Aspen
25 Quaking Aspen
26 Paper Birch
27 Plantation (RP)
28 American Beech
29 Black Cherry
30 Ironwood
31 Noncommercial
32 N. pin oak **
33 Swamp white oak

* Quercus velutina & Q. palustris

** Quercus ellipsoidalis

Random azimuths for transect direction

Az	Az	Az	Az	Az	Az	Az	Az	Az	Az	Az	Az	Az	Az	Az	Az
211	109	248	280	6	51	114	318	71	88	354	275	180	140	256	288
14	329	352	87	208	11	216	317	211	85	259	89	293	345	230	158
245	341	70	26	106	241	264	32	217	136	159	350	68	69	192	190
40	4	38	275	81	41	335	29	41	208	39	112	112	80	223	274
311	260	290	205	30	77	355	51	11	75	181	287	197	11	73	122
312	350	201	71	247	120	14	286	276	189	200	340	10	356	236	102
352	349	289	40	93	175	40	16	13	200	167	213	90	7	158	45
50	204	195	252	297	128	314	185	178	111	151	247	226	66	84	330
300	89	199	72	297	42	100	111	198	55	266	23	233	175	287	137
261	52	172	75	232	328	190	115	293	218	318	348	110	30	45	126
333	310	105	174	278	335	286	19	339	32	210	245	135	185	349	97
150	347	244	250	42	174	79	236	284	166	203	213	245	9	281	112
12	66	288	44	80	133	179	269	148	127	190	349	266	87	169	198
245	181	245	181	73	22	358	317	327	242	220	290	131	286	283	320
23	337	298	66	348	134	179	225	102	251	282	184	70	309	340	265
149	158	166	153	357	32	320	35	14	141	164	79	228	359	307	173
272	107	152	230	88	122	70	44	204	29	252	283	166	169	11	309
125	269	348	165	93	79	80	222	225	82	126	177	22	192	245	105
246	235	50	239	239	63	131	98	309	184	270	177	287	191	174	197
70	80	300	346	74	113	296	346	346	106	303	73	69	238	232	244
197	160	49	72	205	141	134	172	351	272	88	27	268	289	214	283
233	39	47	270	257	354	47	93	56	221	111	241	147	197	198	343
120	117	87	191	247	254	37	17	172	340	222	14	295	309	33	115
191	2	215	301	289	270	339	300	161	293	286	263	134	150	15	160
199	141	42	93	62	322	317	119	161	290	51	340	191	206	244	286
179	44	43	163	114	123	235	336	79	13	34	243	99	142	156	44
2	93	254	335	310	175	257	218	90	155	24	149	128	63	320	80
122	312	197	153	193	195	10	305	189	111	78	108	319	186	227	314
167	159	336	41	314	78	209	68	334	181	332	347	326	343	143	130
294	313	261	339	43	319	204	30	253	49	221	360	185	64	25	176
248	24	200	60	58	262	323	57	296	84	30	11	120	344	304	315
247	126	225	37	110	100	55	211	332	293	257	86	214	134	165	239
98	273	220	78	235	205	168	37	30	151	317	142	130	155	257	179
189	321	19	324	312	22	286	352	176	95	335	244	303	163	126	54
30	327	293	356	149	287	185	76	57	334	179	163	142	246	223	109
71	300	282	88	4	36	286	119	190	50	181	321	238	137	149	326
242	344	7	259	120	224	89	318	60	244	195	234	351	172	53	351
86	206	266	143	167	56	99	77	109	168	289	127	99	224	113	234
10	90	73	144	158	24	255	45	76	231	55	287	171	138	10	97
281	201	294	82	198	216	68	184	77	117	68	214	233	341	139	55
290	123	64	27	265	268	331	159	244	306	321	54	195	154	291	350
64	53	266	291	290	166	278	329	119	197	356	130	294	338	199	80

Stand-Level Site Index Information

STAND LEVEL SITE INDEX INFORMATION

Stand xx Date xx/xx/xx / /87

Point number xxx Recorder

S.I. species [xx]

Species	tree No.	age @ dbh	total Ht.	Site Index	Comments
xx	xx	xxx	xxx	xxx	

Comments:

++

Methods:

1. Measure total height and age at dbh on a minimum of two dominant trees per species
2. The site index trees from the four subplots may be used here, just copy the data and make a note to subplot and tree number in comments.
3. If tree cores show suppression, the tree is rejected.
4. Do not leave the stand [2.47 acres] when looking for SI trees.
5. Species to look for:
   - low sites: black oak, pin oak, white oak
   - medium sites: black oak, white oak, n. red oak
   - high sites: n. red oak, white ash, sugar maple

Ground Flora

HURON-MANISTEE ECOSYSTEM CLASSIFICATION SYSTEM

Attachment 5

STAND 104. SUBPLOT 4. DATE 6-16-86. CREW JEFF RONS RON W

FLORISTICS

EVIDENCE OF DISTURBANCE: WOLF - DOMINATS SOME OPENINGS CLOSED IN BY CANOPY

SUCCESSIONAL STATUS: ARRESTED THIN OAK W/SOME SUGAR MAPLE REGEN + RECRUITMENT

VEGETATION STRUCTURE:

LAYER	COVER CLASS
1. Moss-creeper	R
2. Herbaceous	2
3. Shrub-sapling	10
4. Small tree	10
5. Sub-dominant	2
6. Dominant	80

GENERAL NOTES: 1ST STAND OF SUMMER - CAT. PULKE STAND

CHECK LIST

- VEG STRUCTURE ✓
- SPEC LIST ✓
- FREQ FRAME ✓
- REGENERATION ✓
- MIN N SAMPLES ___

HEIGHT OF BRACKEN: 90 37 40 39 36 39 cm

****

SPECIES LIST

	FREQUENCY 1 2 3 4 5 6	% FREQ	COVER CLASS
FORBS			
Actea pachypoda			
Agrimonia gryposepala			
Antennaria neglecta			
Antennaria plantaginifolia			
Arabidopsis thaliana			
Arabis drummondii			
Artemesia campestris			
Allium tricoccum			
Aralia nudicaulis			
Arisaema atrorubens			
GRASSES			
Agropyron repens			
Agropyron trachycaulum			
Agrostis gigantea			
Agrostis hyemalis			
Agrostis stolonifera			
Andropogon scoparius			
Andropogon virginicus			
Aristida basiramea			
Bromus inermis			

STAND 104 SUBPLOT 4 DATE 6/16

Arisaema triphyllum																			
Amphicarpa bracteata										Cenchrus longispinus									
Anemone canadensis										Cinna arundinacea									
Anemone quinquifolia										Cynosurus echinatus									
Apocynum androsaemefolium																			
Apocynum cannabinum										Dactylis glomerata									
Aquilegia canadensis										Danthonia spicata									
Asarum canadensis																			
Asclepias canadense										Elymus virginicus									
Asclepias incarnata										Eragrostis cilianensis									
Asclepias syriaca										Eragrostis spectabilis									
Asclepias tuberosa																			
Aster laevis																			
										Glyceria canadensis									
Aster lateriflorus										Glyceria grandis									
✓ Aster macrophyllus			2					+		Glyceria striata									
Aster tuberosa																			
Aster puniceus										Leersia oryzoides									
Aster sagittifolius										Leersia cognatum									
Aster simplex																			
										Muhlenbergia frondosa									
Berteroa incana										Muhlenbergia mexicana									
Bidens cernua										Muhlenbergia schreberi									
Boehmeria cylindrica																			
										Oryzopsis asperifolia									
Calla palustris																			
Caltha palustris										Panicum columbianum									
Cardamine bulbosa										Panicum dichotomum									
Caulophyllum thalictroides										✓ Panicum latifolium									+
Centaurea maculosa										Panicum linearifolium									
Cerastium vulgatum										Paspalum ciliatifolium									
Chelone glabra										Phalaris arundinacea									
Chimaphila umbellata										Phleum pratense									
Chondrilla juncea										Poa compressa									
Chrysoplenium americanum										Poa pratensis									
Claytonia virginica																			
Clintonia borealis										Sporobolus cryptandrus									
Cicuta maculata																			
Circaea alpina										UNKNOWN GRASS #1	1	1		6	7	5			10
Clematis virginiana										UNKNOWN GRASS #2	2								R
Coptonia perigrina										UNKNOWN GRASS #3					3				+
Conopholis americana										----------									
Coptis trifolia										----------									
Corallorhiza maculata										----------									
Corallorhiza odontorhiza																			
Cryptotaenia canadensis																			
Cynoglossum officionale										SEDGES									
Cypripedium acaule																			
Cypripedium calceolus										Carex annectens									
										C. bromoides									
Dentaria diphylla										C. cephalophora									
Dentaria laciniata										C. cristatella									
Desmodium nudiflorum										C. digitalis									
Desmodium rotundifolium										C. hystericina									
Dicentra canadensis										C. interior									

STAND 104 SUBPLOT 4 DATE 6/16

| | | |

STAND 104 SUBPLOT 4 DATE 6/16

Lychnis alba									Osmunda cinnamomea							
Lysimachia ciliata									Osmunda claytoniana							
Lysimachia thyrsiflora									Osmunda regalis							
Lycopus americana																
Lycopus uniflorus									Polystichum acrostichoides							
									Pteridium aquilinium							2
Malva moschata																
Medicago lupulina									Thelepteris hexagonoptera							
Medicago alba									T. noveboracensis							
Medeola virginiana																
Melampyrum lineare									_____							
Menispermum canadense									_____							
Mianthemum canadense								R	_____							
Mitchella repens									_____							
Mitella diphylla									_____							
Monarda fistulos									_____							
Monarda punctata																
Monotropa hypopithys																
Monotropa uniflora									MOSSES AND LICHENS							
Oenothera biennis									Atrichum angustatum							
Oxalis stricta									Atrichum crispum							
Osmorhiza chilensis	6	1	2		1			+	Atrichum undulatum							
Panax quinquefolius									Aulocomnium palustre							
Parthenassia glauca																
Pastinacea sativa									Brachythecium sp.							
Pedicularis canadensis									Bryoandersonia illicebra							
Phlox divaricata									Bryum argentium							
Phryma leptostachya									Bauxbaumia aphylla							
Physalis heterophylla																
Physocarpus opulifolius									Campylium chrysophyllum							
Pilea pumila									Campylium stellatum							
Podophyllum peltatum									Ceratodon purpureus							
Polygala paucifolia									Cladonia alpestre							
Polygonatum biflorum					1	1		R	Cladonia capitata							
Polygonatum canaliculatum									Cladonia crista-tella							
Polygonatum pubescens									Cladonia rangiferina							
Polygonum aviculare																
Polygonum hydropiper									Dicranella heteromalla							
Polygonum hydropiperoides									Dicranella varia							
Polygonum persicaria									Dicranum flagellare							
Polygonum punctatum									Dicranum polysetum							
Polygonum tenue									Dicranum scoparium							
Prenanthes alba									Ditrichum pallidum							
Prunella vulgaris									Drepanocladus fluitans							
Ranunculus abortivus																
									Eurynchium hians							
Ranunculus recurvatus																
Ranunculus septentrionalis									Fissidens adiantoides							
Rorippa islandica									Funaria hydrometrica							
Rosa blanda																
Rosa multiflora									Helodium blandowii							
Rosa palustris									Heterophyllum haldinianum							
Rosa rugosa									Hypnum sp.							
Rumex acetosella																

STAND 104 SUBPLOT 4 DATE 6/16

Rumex crispus										Leucobryum glaucum									
Rumex obtusifolius																			
										Mnium affine									
Sanguinaria canadensis										Mnium cuspidatum									
Sanicula marilandica										Mnium insigne									
Saponaria officionalis										Mnium medium									
Sassafras albidum										Mnium punctatum									
Satureja vulgaris																			
Scutellaria lateriflora										Polytrichum commune									
Smilacina racemosa										Polytrichum formosum									
Smilacina stellata										Polytrichum juniperinum									
Solanum carolinense										Polytrichum ohioense									
Solanum dulcamara										Polytrichum piliferum									
Solanum nigrum																			
Stellaria longifolia										Rhytidium rugosum									
Stellaria media																			
										Sphagnum sp.									
Tiarella cordifolia																			
Thalictrum polygamum										Thuidium delecatulum									
Tragopogon dubius										Thuidium recognitum									
Triadenum virginicum																			
Trientalis borealis										_____									
✓Trillium grandiflorum									R	_____									
										_____									
Urtica dioica										_____									
Utricularia vulgaris										_____									
Uvularia grandiflora										_____									
Uvularia perfoliata																			
Verbascum blattaria																			
✓Verbascum thapsus									R										
Verbena hastata																			
Verbena urticifolia																			
Veronica americana																			
Veronica arvensis																			
Veronica serpyllifolia																			
Vicia cracca																			
Viola blanda																			
Viola cucullata																			
Viola eriocarpa																			
Viola lanceolata																			
✓Viola pubescens			1	1					+										
Viola rostrata																			
Viola sororia																			
Viola striata																			
SANICULA TRI FO.			19						+										
LYSIACHIA QUAD.									R										
V8					1				R										

STAND 104 SUBPLOT 4

SHRUBS AND REGENERATION

Acer rubrum	5 11 44 20 11	2
Acer saccarum	3	+
Acer spicatum		
Alnus incana		
Alnus rugosa		
Amelanchier arborea		
Amelanchier laevis		
Amelanchier sanguinea		
Amelanchier spicata		
Betula alba		
Betula alleghaniensis		
Betula lutea		
Betula papyrifera		
Betula populifolia		
Carpinus caroliniana		
Chimaphila umbellata		
Cornus amomum		
Cornus canadensis		
Cornus florida	5	
Cornus obliqua		
Cornus racemosa		
Cornus stolonifera		
Fagus grandifolia		
Fraxinus americana	1 1	+
Hamamelis virginiana		2
Lindera benzoin		
Lonicera canadensis		
" sp	4	
Ostrya virginiana		
Parthenocissus quinquefolia		
Picea pungens		
Pinus banksiana		
Pinus resinosa		
Pinus strobus		R
Populus grandidentata		
Populus tremuloides		+
Prunus serotina	1 1	
Quercus alba	1	+
Quercus rubra	2 3 1	2
Quercus velutina		
Ribes cynosbati		R
Ribes hirtellum		
Rubus alleghaniensis		
Rubus idaeus		
Sambucus pubens		
Sassafras albidum		
Tilia americana		
Thuja occidentalis		
Ulmus americana		
Vaccinium angustifolium		
Vaccinium corymbosum		
Vaccinium stamineum		
Viburnum acerifolium		
Vitis aestivalis		
✓ ABIES BALSAMEA	2 2 1	+
✓ CRATAEGUS SP	1 1	R
✓ LONICERA INVOLUCRATA	1 1	+

REGENERATION

	0.5 - 1.4	1.5 - 2.4	2.5 - 3.4
Acer rubrum			
Acer saccharum			
ABIES BALSAMEA			
Betula alleghaniensis			
Betula papyrifera			
Carpinus caroliniana			
Cornus florida			
Fagus grandiflora			
Fraxinus americana			
Hamamelis virginiana	2		
Ostrya virginiana			
Pinus banksiana			
Pinus resinosa			
Pinus strobus			
Populus grandidentata			
Populus tremuloides			
Quercus alba			
Quercus rubra			
Quercus velutina			
Sassafras albidum			
Tilia americana			

Soils

HURON-MANISTEE ECS STAND NO 60

********** SOILS DESCRIPTIONS dmm 6.10.83 **********

___ MASTER PIT ____SUBPLOT 3 ____(no)

DATE 7/12/84. DESCRIBER _____ RECORDER _____

SOIL SERIES: _____

PHASES: _____

DEPTH OF DUG PIT _____ DEPTH OF BA 110 cm SLOPE(to pit) ____%

DESCRIPTION OF FOREST FLOOR AND SOIL HORIZONS IN PIT

HORIZ/ STRATA	DEPTHS (cm) XX-XX	DEPTH	STRUCT	CONSIST M D	TEXT.	COLOR [1]	ROOTS [2]	GRAVEL [3]	OTHER: SKINS, MOTLS CEM, X, PORES, CONCR	SAMPLES CHK	SAMPLES OFF BD LAB
L		.5									
F		3.5									
H		1.5									
A	0-25	2.5			S	10YR 2/2			SALT & PEPPER		
E	2.5-39.5	37			S	7.5YR 6/4					
BH+M	39-53.5	14		MASSIVE	S	5YR 3/2					
BS1x	53-58	5		MASSIVE	CS	5YR 3/3- 7.5YR 4/5			MOTTLE 5YR 3/5		
BS2x	58-79	21		MASSIVE	CS	5YR 4/3			WET, STANDING 1/20		
B+C	79-98	19		SG	CLS	7.5YR 4/5					
2C	98-110+	≥ 12cm			SI CLAY LOAM	7.5YR 4/4			MOTTLE 10 SOIL FACE 2.5YR 5/2		

[1. SEE ATTACHED [2. Few, Common, Many, & Fine, Medium, Coarse, FOR GR. STR.

[3. %, USE MOTTLE CHARTS, OR EST. BY VOR

EFFECTIVE ROOTING DEPTH _____(cm) TO _____(cm)

REMARKS: BHM IS SOLID ORSTEIN LAYER HAS RANGE IN COLORS AT 5YR 3/2 TO 2.5YR 4/6

APPENDIX B

PRELIMINARY DATA SUMMARIES

Stand number: 36 identifier: New 2-8

---------- SUBPLOT 1 SUMMARY ----------

Species	BA	NOT	MDBH	VOL	SI
White Ash	10	21	9.3	310	0
N. Red Oak	50	46	14.1	1658	76
Beech	10	99	4.3	68	0
Black Cherry	10	16	10.8	284	60
Subplot mean	80	182	9.0	2320	

MAI= 39 cf/ac/yr (gross) age= 60 yrs
10 yr PAI: 49 cf/ac/yr 0.13 inches/yr dbh

Stand number: 36 identifier: New 2-8

---------- SUBPLOT 2 SUMMARY ----------

Species	BA	NOT	MDBH	VOL	SI
White Ash	30	45	11.1	916	78
N. Red Oak	10	9	13.9	344	83
Beech	60	80	11.8	1675	0
Subplot mean	100	134	11.7	2935	

MAI= 48 cf/ac/yr (gross) age= 62 yrs
10 yr PAI: 57 cf/ac/yr 0.13 inches/yr dbh

Stand number: 36 identifier: New 2-8

---------- SUBPLOT 3 SUMMARY ----------

Species	BA	NOT	MDBH	VOL	SI
Basswood	50	73	11.2	1728	0
Sugar Maple	60	205	7.3	1573	66
White Ash	30	53	10.2	1096	85
Black Cherry	10	17	10.4	307	79
Subplot mean	150	348	8.9	4705	

MAI= 81 cf/ac/yr (gross) age= 58 yrs
10 yr PAI: 87 cf/ac/yr 0.13 inches/yr dbh

Stand number: 36 identifier: New 2-8

---------- SUBPLOT 4 SUMMARY ----------

Species	BA	NOT	MDBH	VOL	SI
Red Maple	10	11	12.9	343	78
Sugar Maple	10	68	5.2	0	0
White Ash	10	13	11.9	342	0
N. Red Oak	20	14	16.0	735	83
Beech	10	26	8.4	0	0
Subplot mean	60	132	9.1	1419	

MAI= 23 cf/ac/yr (gross) age= 63 yrs

10 yr PAI: 30 cf/ac/yr 0.14 inches/yr dbh

Stand number: 36 identifier: New 2-8

---------- STAND SUMMARY: PER ACRE MEANS ----------

Species	BA	NOT	MDBH	VOL	SI	RF	IV
Red Maple	3	3	12.9	86	78	25	29
Basswood	13	18	11.2	432	0	25	47
Sugar Maple	18	68	6.9	393	66	100	152
White Ash	20	33	10.5	666	82	50	87
N. Red Oak	20	17	14.5	684	80	50	79
Beech	20	51	8.5	436	0	75	121
Black Cherry	5	8	10.6	148	70	75	84
Overall mean	98	199	9.5	2845			
Std. Error	19.3	50.9		693.8			
CV%	40	51		49			

MEAN MAI= 48 cf/ac/yr (gross) age= 61 yrs

MEAN 10 yr PAI: 56 cf/ac/yr 0.13 inches/yr dbh

Ground Flora Data Summary

ECS Ground Flora Summary — March 1987

STAND	SPECIES	% FREQ.	% COVER	MEAN RANK
105	Acer rubrum	29	20	4.75
105	Acer saccharum	4	7	3.75
105	Actaea rubra	4	< 5	2.75
105	Amelanchier sp.	4	< 5	1.50
105	Aralia nudicaulis	4	< 5	2.25
105	Arisaema triphyllum	4	< 5	2.50
105	Carex pensylvanica	4	< 5	2.00
105	Carex sp.	0	< 5	1.75
105	Carex tenera	4	< 5	2.00
105	Cornus alternifolia	0	< 5	3.00
105	Fagus grandifolia	21	< 5	2.75
105	Fraxinus americana	96	10	4.00
105	Galium triflorum	0	< 5	0.50
105	Hamamelis virginiana	0	< 5	1.25
105	Hieracium aurantiacum	0	< 5	0.25
105	Hystrix patula	8	< 5	0.75
105	Lonicera canadense	0	< 5	0.25
105	Lonicera sp.	0	< 5	0.75
105	Maianthemum canadense	29	< 5	0.50
105	Medeola virginiana	0	< 5	1.25
105	Mnium sp.	4	< 5	0.25
105	Oryzopsis asperifolia	4	< 5	2.25
105	Ostrya virginiana	8	< 5	0.25
105	Populus grandidentata	0	< 5	1.50
105	Populus tremuloides	0	< 5	0.25
105	Prenanthes alba	0	< 5	1.00
105	Prunus serotina	4	< 5	0.50
105	Quercus rubra	4	< 5	1.25
105	Ribes cynosbati	0	< 5	1.50
105	Solidago caesia	0	< 5	2.50
105	Streptopus roseus	0	< 5	1.00
105	Taraxicum officionale	4	< 5	2.00
105	Trientalis borealis	0	< 5	2.75
105	Trillium grandiflorum	0	< 5	1.25
105	Unknown grass	0	< 5	2.00
105	Viburnum acerifolium	0	< 5	3.00
	Number of species =	36		

Soil Data Summary

SOILS DATA FORM FOR/USFS ECS RESEARCH (JBH/2.83) Pg 2 Stand 54

Uniform Coding Conventions: slash-0 means unknown/missing, blank means not applicable, 500 means below 450cm

***** EDAPHIC/GEOLOGIC PROFILE VARIABLES ********** Coder B Date 4.17.84

Stand Number (1-60) & File #

Stand	Pit/Plot 4	Plot 1	Plot 2	Plot 3	(use 2nd form for plots 5 & 6)
					Soil Taxonomy Series Code (see legend)
					Soil Mapping Unit Code (See legend)
					O2 Thickness (cm) Rem
					A1 thickness (cm) Rem
5	10 3/3	10 4/6	10 3/1	N 3/0	value
					E Thickness (cm) Rem
					Thickness Code (0=absent; .1=disc 0-.15cm; 1=.15-1.25cm; 2=1.25-5cm; 5=5-10cm; 10=10+cm)
	S	LMS			Waviness (0=non-wavy; 1=wavy; usually thick > 5 cm or 2")
LS					Texture of upper 30cm (12", use dominant text re regeneration)
					B Depth to (cm) Rem
	10 5/6	→	→	10 5/8	B1 Intensity/development of Bs, Bhs, Bh) (1=7.5YR5/6 or lighter; 2=not 1 or 3; 3=darker than 7YR4/4=3)
					Value
					Bs Thickness (cm, 0 if absent) Rem
					Thickness code (0=44; 45=45-59; 60=60-74; 75=75+)
					Bhir Thickness (cm, 0 if absent) Rem
					Thickness code (0=44; 45=45-59; 60=60-74; 75=75+)
LS					B Dominate Texture (use dominant texture deteraining growth)
30	37	74	66	62	C depth to
					Depth to Groundwater Table or Mottles (of chroma(=2) (cm)
					Depth to mottles indicating seasonal high water table (cm)
					Soil Drainage Class Code (See legend and diagram)
					Dominant texture top 150cm (4.92 ft)
					Dominant texture 150-450cm (4.92-14.76 ft)
					Dominant texture of soil & strata to 450cm
	0		0	0	Banding/varve Code (0=absent; 1=varves; 2=<5cm, 5=5-10cm; 10=15+cm
					Thin band (<5cm or 2") Depth to in cm
					Texture of Thin Band
					Medium band (5cm - 15cm or 6") Depth to in cm
					Texture of Medium Band
					Thick band (>15cm or 6") Depth to in cm
					Texture of Thick Band
					Texture of heaviest band
					Predominant Banding Texture (blank, VFS, LS, SL, SCL=SCL/heavier)
					Depth (cm) to accumulate VFS banding over 15cm/6" thick (500=none)
					Depth (cm) to accumulate LS banding over 15cm/6" thick
					Depth (cm) to accumulate SL banding over 15cm/6" thick
					Depth (cm) to accumulate SCL or heavier banding over 15cm/6" thick
					# retaining discontinuities to depth of 150cm/4.92 ft
					# retaining discontinuities to depth of 450cm /19.76 ft
					Depth (cm) to till (>15cm (6") thick, SCL+, with gravel; 500=none)
					Depth (cm) to pH 7 material
					Depth (cm) to calcareous material (pH 8.1 or greater)
V					Effective rooting depth (cm)

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☆U.S. GOVERNMENT PRINTING OFFICE: 1993 - 759-352/80099

Host, George E.; Ramm, Carl W.; Padley, Eunice A.; Pregitzer, Kurt S.; Hart, James B.; Cleland, David T.

1992. **Field sampling and data analysis methods for development of ecological land classifications: an application on the Manistee National Forest**. Gen. Tech. Rep. NC-162. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 47 p.

Presents technical documentation for development of an Ecological Classification System for the Manistee National Forest in northwest Lower Michigan, and suggests procedures applicable to other ecological land classification projects. Includes discussion of sampling design, field data collection, data summarization and analyses, development of classification units, and validation.

KEY WORDS: Multivariate methods, ordination, ground flora, soils, physiography.

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Our job at the North Central Forest Experiment Station is discovering and creating new knowledge and technology in the field of natural resources and conveying this information to the people who can use it. As a new generation of forests emerges in our region, managers are confronted with two unique challenges: (1) Dealing with the great diversity in composition, quality, and ownership of the forests, and (2) Reconciling the conflicting demands of the people who use them. Helping the forest manager meet these challenges while protecting the environment is what research at North Central is all about.